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AT MCAS (MARINE CO..(U) NAVAL CIVIL ENGINEERING LAB
PORT HUENEME CA M C HIRONAKA ET AL. JAN 86
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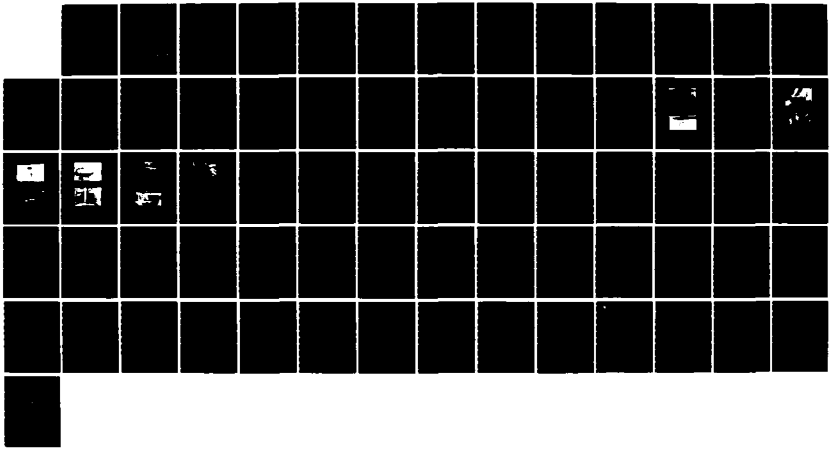

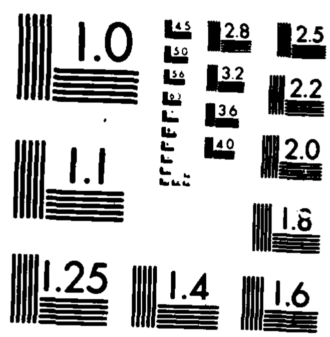

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NCEL
Technical Note

By M C Hironaka
and T J Holland

Sponsored by
Marine Corps

Blistering of Asphalt Pavement Overlay on Runway 14-32 at MCAS Beaufort, South Carolina

ABSTRACT The objectives of this investigation were to determine the primary cause of the blistering of the 1-1/2-inch AC overlay on Runway 14-32, Marine Corps Air Station, Beaufort, S.C., and to recommend a repair alternative for the pavement. Pavement temperature profiles and blister surface elevation changes were measured in field tests. Samples of the blister gas and of the overlay were evaluated in laboratory tests. The test results led to the conclusion that the blister behavior is diurnal in nature and is caused by thermodynamic effects on the air and water vapor trapped at the overlay-substrate interface where disbonding is present. Because of the presence of these disbonded areas and the possibility of blisters forming even with an additional overlay, it is ~~we~~ recommended that the present overlay ~~be~~ removed and replaced in accordance with standard pavement overlay construction practice.

NAVAL CIVIL ENGINEERING LABORATORY PORT HUENEME CALIFORNIA 93043

METRIC CONVERSION FACTORS

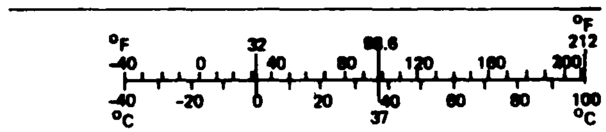
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2,000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1,000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The objectives of this investigation were to determine the primary cause of the blistering of the 1-1/2-inch AC overlay on Runway 14-32, Marine Corps Air Station, Beaufort, S.C., and to recommend a repair alternative for the pavement. Pavement temperature profiles and blister surface elevation changes were measured in field tests. Samples of the blister gas and of the overlay were evaluated in laboratory tests. The test results led to the conclusion that

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20. Continued

the blister behavior is diurnal in nature and is caused by thermodynamic effects on the air and water vapor trapped at the overlay-substrate interface where disbonding is present. Because of the presence of these disbonded areas and the possibility of blisters forming even with an additional overlay, we recommended that the present overlay be removed and replaced in accordance with standard pavement overlay construction practice.

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Naval Civil Engineering Laboratory
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and Appendix D

Delete the proprietary statements in
Appendix C of this report. The U. S.
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Per Mr. Triem, NCEL/Publications

INTRODUCTION

Objectives

The first objective of this investigation was to identify the primary cause of the blistering (Figures 1 and 2) of the 1-1/2-inch thick asphalt concrete (AC) pavement overlay on Runway 14-32 at the Marine Corps Air Station (MCAS), Beaufort, South Carolina that occurs during the warm summer months. A subsequent objective was to establish a repair alternative for the existing pavement.

Background

The Southern Division, Naval Facilities Engineering Command (SOUTHDIV) performed a study of the blistering problem during the summer of 1984 through a contract with PSA Engineers of Dallas, Texas. The results of that study are reported in Reference 1. Since SOUTHDIV felt that a definitive cause of the blistering problem was not determined in that study, they asked the Naval Civil Engineering Laboratory (NCEL) to conduct further investigations of the blistering problem (Reference 2). Funding authorization for the study proposed by NCEL in response to Reference 2 was received on 2 July 1985.

The investigation reported in Reference 1 was conducted in two phases. In Phase I, PSA Engineers concluded that the most probable cause of the blisters is the generation of gas resulting from the heating of trapped or absorbed moisture by incident solar energy. It was further concluded that the moisture originated from the subsurface area under the runway and migrated through the relatively permeable underlayers of the pavement and was then trapped under the impermeable overlayer. In Phase II, they concluded that circumstantial evidence showed that the cause of the blisters was probably due to carbon dioxide gas and water vapor originating from the subsurface. The results of our investigation do not support either of these conclusions.

The construction history of the overlay is shown in Table 1. The blistering of the complete 1-1/2-inch thick overlay has occurred in both the single bituminous surface treatment and pavement reinforcing fabric interlayer areas since 1982, the second summer after the overlay was installed. Currently (1985), the blisters occur more prevalently in the pavement reinforcing fabric interlayer areas. The blisters range in diameters from a few inches to more than 4 feet.

The pavement reinforcing fabric installation began in mid December 1980. Problems were encountered with achieving the specified 98% compaction of the overlay. An AC-20 asphalt cement was used in the overlay mix. Because of adverse weather, construction was suspended till April 1981. During both periods of construction, AC-20 was used beneath the pavement reinforcing fabric as a tack coat and no asphalt was applied on the fabric prior to the overlay.

The blistering problem appears to be related to construction procedures or materials used in the construction because the blisters are more prevalent in certain paving lanes. Where the asphalt mix design was changed, little to no blisters have occurred.

FIELD MEASUREMENTS AND OBSERVATIONS

During the week of 23 August 1985, NCEL engineers made the following measurements, observations and samplings on Runway 14-32:

- Pavement temperature profiles at two locations
- Elevation changes of the surface of four blisters
- Sampling of gas contained in four other blisters
- Sampling of the blistered asphalt overlay at two blisters
- Saw cutting and inspecting of five additional blisters

The locations where measurements of pavement temperature profiles and blister elevation changes were made and where samples of the asphalt overlay were taken are shown in Table 2. Locations and ambient conditions for the four blister gas samples are shown in Table 3. The locations on Runway 14-32 where the measurements and samples were taken are shown in Figure 3.

Pavement Temperature Profiles

Profiles of the pavement temperatures were measured with thermocouples. The thermocouples were installed as follows:

- A 1-inch diameter hole by 24 inches deep was drilled through the pavement structure.
- The prebundled thermocouples (Figure 4) were placed in the hole so that the first thermocouple was at the surface and the remaining thermocouples were positioned at every 1/2 inch for the first 6 inches and at 12, 18, and 24 inches.
- The hole was then sealed with an adhesive grout epoxy resin (two component Federal Spec MMM-A-001993 and 8040-00-726-3567) containing added sand (Figure 5).

The thermocouples were installed at two locations. At the first site, readings were taken automatically with a Kaye, Inc., Digistrip III Datalogger* shown in Figure 6. At the second site, readings were taken manually with a Fluke, Inc., Model 2166A, 10-channel digital thermometer (Figure 7) and automatically with the Datalogger.

*Manufacturers names and model numbers for instrumentation and equipment used in the tests are identified for record purposes only. Their use does not constitute endorsement of the products by the Navy or the Federal Government.

Blister Behavior

The behavior of four blisters were monitored using a Carl Zeiss, Inc., Model NI-2 Automatic Universal Level. Each blister was first marked with two perpendicular lines that were approximately aligned north-south and east-west. The intersection of these lines was at the apex of the blister. Each line was marked in 4-inch increments as shown in Figure 8. Readings were taken periodically with the level at each marked location on each line of each blister using a bench mark that was established off the runway at each of the two sites. A standard level rod with a modified contact base, as shown in Figure 9, was used. Readings were taken to the nearest 0.0025 foot (0.03 inch).

Gas and Pavement Samples

Samples of the gas in four blisters (different from those monitored above) were taken with the gas extractor shown in Figure 10. Gas samples were taken from different blisters at a later time because the monitored blisters were not formed at the planned time for gas and pavement sampling due to the effects of an approaching hurricane (Elena). In taking each sample, a 1-inch diameter hole about 1-inch deep was drilled at the apex of the blister. The probe of the sampler was then inserted into this hole and driven the remaining 1/2 inch into the blister. The needle valve in the probe was then opened to create a direct conduit from within the blister to the sample container. The "O" ring on the exterior of the probe acted as a seal to prevent atmospheric air from entering the blister and contaminating the sample. By opening the valve to the evacuated stainless steel container, the vacuum in the container caused the gas sample to be extracted from the blister and into the container. The valve was then closed and the device was retracted from the hole. This same procedure was repeated at three other blisters.

The equipment shown in Figure 11 was used to cut out samples from two blisters and to open five other blisters for inspection. Six samples, each 6 inches square by 1-1/2 inches thick, of the overlay from blisters 1 and 3, the behavior of which were monitored earlier, were taken for evaluation in the laboratory. No cooling water was used during saw cutting so that inspection for moisture at the overlay-substrate interface could be made.

Several significant observations were made during the saw cutting operations. After the cutting was completed over each blistered area, the overlay was easily removed by prying with a screwdriver; that is, the overlay was not bonded to the substrate. Where the pavement reinforcing fabric interlayer was present, it was either not bonded or could easily be peeled off from the overlay and the substrate. Figure 12 shows the pavement reinforcing fabric interlayer exposed after removing the pavement samples from blister 1. After the cut pieces were removed from the holes, some of the holes were observed to contain several small droplets of water. Also the removed overlay samples had small but visible cracks on the surface. At the cut edges, some of the cracks, although sealed, extended completely through the overlay. In all cases, the measured thickness of the overlay removed from each hole was 1-1/2 inches.

TEST RESULTS

Measured temperatures at Sites 1 and 2 near blisters 1 and 2 and blisters 3 and 4, respectively, are contained in Appendix A. For comparison purposes, the ambient air temperature and precipitation data that were taken routinely as part of the operation at MCAS, Beaufort, are included in Appendix B. Plots of the temperature profiles at the two sites at various times during the day over a 2-day period are shown in Figures 13 and 14. These plots show that there is a lag time between the occurrence of the surface temperature and its effect at depths within the pavement structure. Note that the largest daily temperature excursion (from about 80°F to 108°F) occurs within the upper 2 inches of the pavement structure. Below this depth, the large diurnal surface temperature variation diminishes to approximately a steady state condition between the temperatures of 90°F to 94°F at about the 1 foot depth. Because the blisters have a diurnal behavior, the cause of the blistering is temperature related and thus, must be situated shallower than 1 foot in the pavement profile.

The blisters rise and fall throughout each day with changes in ambient pavement temperatures as shown in Figures 15 through 18. During the cool morning hours, the blisters are absent. As the pavement temperature increases, the blisters begin to rise. Subsequently, as the temperature decreases, the blisters recede. When they are punctured, the blisters deflate. This implies that they are caused by internal pressure buildup. The blister volume changes calculated with the blister surface elevation data are shown in Table 4.

The gas samples from the four blisters were analyzed for saturates, unsaturates, and normal gases in a Hewlett-Packard Gas Chromatograph (Model 5880). The results of the analyses are shown in Appendix C. Figure 19 summarizes all of the detected constituents of the gas samples as compared to the constituents contained in air. The constituents of the blister gas are the same as those found in normal air. The deviation of the amounts of each constituent from the norm is explained later in this report.

Gas samples collected from the AC pavement overlay itself at various laboratory temperatures are shown in Appendix D. The gas samples were collected from the AC pavement samples that were obtained during the saw cutting operation. Emitted gases were collected at ambient laboratory temperature and at 100 and 125°F. The collected samples were then analyzed using the same chromatograph as was used for the blister gases. Figure 20 summarizes the test results. These results show that the gas contained in the pavement itself is principally air and that there were no other gases emitted in any measurable amount that could be responsible for the pavement blistering.

The results of the laboratory evaluation of the AC overlay samples of blisters 1 and 3 are shown in Appendix E. The results of this analysis does not show any unusual findings that could be attributed to the cause of the blisters.

POSSIBLE REASONS FOR BLISTERING

An NCEL team of engineers and scientists with technical expertise in pavements, structural mechanics, thermodynamics, chemistry, and biology evaluated possible reasons for the blistering of the overlay. Possible reasons for the the blisters considered included:

- Thermal expansion of entrapped gases
- Thermal expansion of the pavement overlay
- Gas pressures originating from below the pavement (e.g. the ground water)
- Gas creating chemical activity
- Gas creating biological activity

Of the five reasons listed, thermal expansion of trapped gases (including water vapor) beneath the overlay is the most feasible cause of the blistering. Because of the diurnal nature of the behavior of the blisters, the gases must be trapped. The blistering cannot be attributed to a continuously accessible diurnal source of new gases because if such a source was present, the same passageway would cause the pressures to vent and thus blistering would not occur. Additionally, a continuous diurnal source of new gases necessarily means exposure to ambient atmospheric conditions.

Thermal expansion of the pavement overlay occurs (as observed in field elevation measurements) but it is not the primary cause of the blistering. The fact that the blisters deflate upon puncturing shows that the blisters are caused primarily by internal pressures and not by buckling due to thermal expansion of the overlay itself.

It is unlikely that gas pressures originating from ground water or moisture in the soil could be the cause of the diurnal blister behavior. As can be seen in the measured temperature profiles of Figures 13 and 14, the large diurnal pavement surface temperature variation dissipates into a steady state condition below about the 1-foot depth. Thus, since diurnal temperature effects are minimal beyond this depth, the blister behavior cannot be attributed to gas originating from deeper depths on a diurnal basis. Since the ground water table is located much deeper than 1 foot (10-foot deep inspection wells were dry), this eliminates gas originating on a diurnal basis from the groundwater as the cause of the blisters. Gas originating from moisture in the soil at shallower depths above the water table can also be eliminated as the cause of the blisters because of two reasons: (1) the soil, which is sandy, is much more permeable to gases than the dense asphalt pavement layers and thus any pressure buildup will dissipate through the soil and not through the pavement structure, and (2) gases present in the soil moisture, if they were to migrate into the blisters, would with time become depleted and blisters would cease to form. Since the blisters continue to form diurnally, blister formation cannot be attributed to gas pressure buildup in the soil layers beneath the pavement structure. An additional indication

that the cause of the blisters is not deep seated (i.e., areas below the pavement, e.g., ground water) is the fact that the blisters are concentrated in certain paving lanes.

It is unlikely that chemical activity is responsible for the formation of the blisters because the materials used in constructing the pavement are chemically stable to begin with. Additionally, any gas producing chemical reaction occurs in one direction and the resulting products are more stable than the initial components. To reverse such reactions, considerable energy and possibly a catalyst is required. Such required energy is not available in the pavement to cause the diurnal effects. Also, if chemical reactions were responsible for the formation of some of the gases, the amount of gas generated would be on a diminishing basis since the reactive components would be depleted. Since the blisters have occurred regularly, chemical activity is not responsible for the diurnal gas pressure buildup and blister formation.

Biological activity may be involved initially in forming some of the gases contained in the blisters but such activity is not likely to be responsible for the subsequent continuing diurnal behavior of the blisters. Both aerobic and anaerobic organisms require water to thrive. Additionally, in the case of aerobic organisms, oxygen is required. When selected blisters were opened, some of the blisters contained several small droplets of water and other blisters could have been damp but not visibly noticeable. Thus, it is feasible that some biological activity could take place within the blisters.

The analysis of the gas contained in the blisters suggests that biological activity, if present, is primarilly aerobic and that the activity level is low. Aerobic activity is substantiated by the fact that there is a high concentration of carbon dioxide and a low methane content (methane is produced by anaerobic organisms). The abundant supply of oxygen is indicative of low biological activity. The high carbon dioxide content of the blisters suggest that the blister gases are not able to dissipate to ambient values; this indicates that the gases are contained in a sealed environment. In addition to biological activity, the excess carbon dioxide could have originated from that dissolved in rain water that percolated through the pavement overlay.

For aerobic biological activity to be responsible for the diurnal blister behavior, it is necessary to have an unsealed environment for oxygen replenishment to occur on a continuous and steady-state basis. If such an environment was present, the diurnal pressure buildup within the blisters could not occur because the generated gases could escape through the same passages from which the continuous oxygen supply was obtained to sustain such biological activity. Thus, biological activity can be eliminated as the primary cause of the diurnal blistering of the pavement overlay.

Thermal expansion of trapped gases, therefore, provides the most feasible explanation for the diurnal blistering of the overlay. Subsequent analyses investigate this further.

BLISTER GAS THERMODYNAMIC ANALYSIS

An evaluation was made to determine if the blister formation could be explained by thermodynamic behavior of the blister gases (Ref 3).

The first evaluation was made considering only the blister gas. Treating the gas as an ideal gas that is subjected to a temperature increase from 80°F to 120°F, the increase in volume is given by:

$$V_2 = V_1 \left(\frac{T_2}{T_1}\right)\left(\frac{P_1}{P_2}\right) \quad (1)$$

where: V_1 = initial volume

V_2 = final volume

T_1 = initial absolute temperature

T_2 = final absolute temperature

P_1 = initial absolute pressure

P_2 = final absolute pressure

Maximum volume increase would occur when $P_1 = P_2$ which reduces the equation to:

$$V_2 = V_1 \frac{T_2}{T_1}$$

$$= \frac{580}{540} V_1$$

$$= 1.074 V_1$$

This relationship shows that expansion of the gas in the blister accounts for a maximum of 7.4% increase in volume when the above temperature change is experienced. Since this does not account for all of the volume changes shown in Table 4, there must be other causes that account for the remaining volume change. In the above equation, if $V_1 = 0$, this means that the overlay was not disbonded from the substrate (i.e., no void space present) and thus blistering would not occur. Once a blister exists, this equation will provide estimates of volume changes in the blister.

A second evaluation was made assuming there was moisture in the blister and that the vapor from the evaporation of this moisture was responsible for part of the pressure buildup and thus some of the volume change. As the temperature increases, available free water can evaporate and create additional pressure. The partial pressure of a gas in a mixture of ideal gases is the same as the pressure which that gas alone exerts in the same volume as the total mixture at the same temperature (Ref 3). Since the blister gases and water vapor are assumed to behave according to the ideal gas law, their partial pressures are additive. Thus, the total blister pressure can be computed by:

$$P = P_g + \phi P_{sv} \tag{2}$$

where: P = total pressure in the blister assuming no change in volume

P_g = pressure due to temperature increase of contained gases (computed from Equation 1)

ϕ = relative humidity

P_{sv} = saturated water vapor pressure

The equivalent pressure of the weight of the 1-1/2-inch overlay is:

$$p_o = \gamma_a t$$

$$= (141 \text{ lb/ft}^3)(1.5 \text{ in.})/(1{,}728 \text{ in.}^3/\text{ft}^3)$$

$$= 0.12 \text{ psi}$$

where: p_o = pressure equal to the weight of the overlay

γ_a = density of asphalt overlay

t = thickness of the overlay

At State 1, T = 80°F. Assume the relative humidity of the water vapor is at 100% and the pressure of the gas is at atmospheric plus the pressure equivalent to the weight of the asphalt overlay (i.e., 14.8 psi). The existing blister pressure is computed from Equation 2 to be:

$$P = (14.7 + 0.12) + 1(0.51)$$
$$= 15.33 \text{ psi}$$

The differential pressure of 0.53 psi is small enough not to cause noticeable blistering.

At State 2, although the relative humidity within the blister can vary, it is assumed to be 100% such that the maximum blister pressures are computed. Using Equations 1 and 2 with initial conditions at 80°F and 14.8 psia, the theoretical blister pressures at various temperatures that could result if no volume change occurred are:

Temperature (°F)	Gas Pressure (psia)	Vapor Pressure (psia)	Differential Pressure (psi)
100	0.6	0.9	1.5
110	0.8	1.3	2.1
120	1.1	1.7	2.8
130	1.4	2.2	3.6
140	1.6	2.9	4.5

The differential pressures cause the blisters to occur. Since volume changes do occur, the indicated differential pressures are dissipated to an equilibrium state such that the weight of the overlay and the deflected shape of the blister is maintained. For the measured volume changes shown in Table 4, the differential pressure that caused the blister growth was about 1.7 psi for a temperature of approximately 105°F at the base of the overlay. The actual temperature profile through a blister was not measured but in the Reference 1 study, it was determined to be only several degrees higher than areas that were not blistered. In the course of the field investigations, pavement surface temperatures as high as 135°F were measured. Thus, it is feasible that pressures in the 3 to 4 psi range could occur resulting in the formation of the blisters.

The following analysis was performed to determine if the amount of water required to cause the blister growth was reasonable. The mass ratio of moisture to gas in the blister can be related to the relative humidity by:

$$\gamma = \phi \frac{v_g}{v_{sv}} \tag{3}$$

where: $\gamma = \dfrac{M_w}{M_g}$ = mass ratio of moisture and gas

M_w = mass of moisture

M_g = mass of gas

$\phi = \dfrac{P_w}{P_{sv}}$ = relative humidity

P_w = partial pressure of moisture

P_{sv} = partial pressure of saturated vapor

v_g = specific volume of gas

v_{sv} = specific volume of saturated vapor

Using the ideal gas law, the mass ratio is:

$$\gamma = \phi \frac{R_g\, T_g\, P_{sv}}{R_{sv}\, T_{sv}\, P_g}$$

where: $T_g = T_{sv} = T_{blister}$

$R_g = \dfrac{R}{M_g}$

$R_{sv} = \dfrac{R}{M_{sv}}$

where: $m_{sv} = 18\ lb_m/lb_{mole}$

R = Universal gas constant

$= 1{,}545\ ft\text{-}lb_f/lb_{mole} - {}^\circ R$

The gas composition was assumed to be 10% carbon dioxide, 10% oxygen, and 80% nitrogen by volume (See Appendix C). The molecular weight of this mixture is given by:

$$m_g = \frac{(0.1)\ (44) + (0.1)\ (32) + (0.8)\ (28)}{0.1 + 0.1 + 0.8}$$

$$= 30\ \frac{lb_m}{lb_{mole}}$$

Inserting the respective masses, the mass ratio is:

$$\gamma = 0.6\ \phi\ \frac{P_{sv}}{P_g} \tag{4}$$

By Equation 4, the mass ratio at 80°F and 100% relative humidity is:

$$\gamma_{80} = \frac{0.6\ (1)\ (0.5067)}{14.8}$$

$$= 0.0205$$

Similarly, the mass ratio at 105°F and 100% relative humidity is:

$$\gamma_{105} = \frac{0.6\ (1)\ (1.1120)}{14.8}$$

$$= 0.0451$$

By Equation 3, the amount of additional water in vapor form that could contribute to blister growth is:

$$M_w = (\gamma_{105} - \gamma_{80})\ M_g$$

$$= (0.0451 - 0.0205)\ M_g$$

$$= 0.0246 M_g \tag{5}$$

The mass of gas required in the above equation can be computed using measured blister values as shown in Table 4:

$$M_g = \frac{P_g V_g}{R_g T_g}$$

but: $R_g = \frac{R}{m_g}$

$$M_g = m_g \frac{P_g V_g}{R T_g}$$

$$M_g = \frac{(30 \text{ lb}_m/\text{lb}_{mole}) (14.8 \text{ lb/in.}^2) (196 \text{ in.}^2)}{(1{,}545 \text{ ft-lb}_f/\text{lb}_{mole} \text{ °R}) (565\text{°R}) (12 \text{ in./ft})}$$

$$= 0.0083 \text{ lb}$$

Substituting this mass of the gas in Equation 5 gives:

$$M_w = 0.0246 (0.0083 \text{ lb}_{mole})$$

$$= 0.000204 \text{ lb}_m$$

This mass of water is equivalent to about 0.1 cm³. It is reasonable that this amount of water could be present in the blister and, therefore, contribute to the formation of the blisters. At 105°F, the computed mass of water above would occupy the following volume under saturated conditions:

$$V_{wv} = M_w v_w$$

$$= (0.000204 \text{ lb}_m) (307.9 \text{ ft}^3/\text{lb}_m) (1{,}728 \text{ in.}^3/\text{ft}^3)$$

$$= 109 \text{ in.}^3$$

This computed volume is also reasonable.

It is, therefore, concluded that the blister formation is due to thermal effects on the entrapped gases and water vapor.

FINITE ELEMENT CALCULATIONS

Calculations were made to determine the magnitudes of the internal pressures that are required to raise the blisters at various temperatures. These are pressures that are needed to overcome both the weight, bending stiffness, and membrane tension of the overlay at the respective temperatures. The ADINA finite element program (Ref 4) was used to determine the required internal pressures. The characteristics and behavior of blister 1 was chosen for simulation with the finite element model. Heights along the four radials were averaged (with the vertical expansion of the pavement subtracted out) to determine an approximation of the deformed shape. The profile obtained by averaging the data is shown in Figure 21. The finite element mesh shown in Figure 22 was used to model the symmetric half of a 24-inch radius blister in the 1-1/2-inch overlay.

The model uses 8-node axisymmetric quadrilateral elements. The model is intended to simulate a blister with no bonding of the overlay with the base except at the blister perimeter. Along the perimeter, the bonding is perfect between the base and the overlay (i.e., no vertical or horizontal movement can occur). The additional elements along the bonded edge are included to account for thermal expansion of the overlay.

Thermal expansion of the overlay was computed with coefficients presented in Reference 5. Its effect on the behavior of the blister was minor.

Calculations were made with the finite element model to simulate the behavior of blister 1 at selected temperatures. The constitutive properties for the asphalt pavement at the temperatures used in the analyses are shown in Table 5. The results of the calculations are summarized in Figure 23. As the temperature increases, the required pressure to obtain the same crown deflection of 0.69 inch as was observed in blister 1 decreases. At 105°F, a pressure of almost 6 psi is required to achieve the same crown deflection. This pressure is considerably higher than the 1.7 psi calculated in the thermodynamic analysis for the same temperature. It is believed that this difference between the calculated pressures exist because: (1) the finite element program treats the asphalt overlay as a homogeneous material, (2) cracks are present in the blistered overlay (most of the blisters had cracks at the apex) which reduces the bending stiffness, (3) the actual temperature could be several degrees higher (Ref 1) than that measured because of the insulating effect of the trapped gases (i.e., the subsurface layers act as a heat sink), and (4) the assumed initial starting point of 80°F used in the thermodynamic analysis may be higher than actual field conditions. Also, the calculated pressure by the finite element method is quite sensitive to the assumed radius of the blister (see Figure 23). Therefore, since the blister did occur at the 105°F temperature, the finite element model does not fully represent the actual field conditions of blister 1. However, at temperatures higher than about 127°F (see Figure 23), the pressures calculated by the thermodynamic expansion of the gas and water vapor contained in the blisters exceed those computed by the finite element method. Thus, the probability of blisters forming is high at those temperatures.

An analysis was made to determine the effect of a 2-inch overlay on the pavement in its present condition with the 1-1/2-inch overlay in place. The finite element model was modified to analyze a 2-inch overlay. Although not entirely correct, it was assumed that the new overlay provided resistance to all of the bending and membrane stresses and that the present overlay was cracked. The results of this analysis are summarized in Figure 24 where it can be seen that significant blister crown deflections were calculated. Thus, although not entirely conclusive with the above limited information, the possibilities are good that blistering will occur even with the added 2-inch overlay.

FINDINGS

1. The blistering of the AC pavement overlay occurs on a diurnal basis and is directly proportional to temperature. That is, the blisters are absent during cool conditions (e.g., early morning, cloudy, or rainy times), gradually rise as temperatures increase and recede as temperatures decrease in the late afternoon and evening.

2. The blisters deflate when punctured. Thus, the blisters are caused by buildup of internal pressures and are not due to thermal expansion of the overlay itself. The pressure buildup occurs because the gas within each blister is in a contained/sealed environment.

3. The effect of diurnal temperature changes at the pavement surface dissipates into a steady state condition at about the 1-foot depth. Thus, the diurnal blister behavior causative factor must, therefore, occur within this first foot of the pavement structure and is not deep seated, for example, originating from the ground water or other areas below the pavement structure.

4. The cause of the blistering is due to expansion of gases (including water vapor) that are trapped at the overlay substrate interface.

5. Blistering of the overlay occurs where bonding of the overlay to the substrate is deficient. Currently, blisters are more prevalent where the pavement reinforcing fabric interlayer was installed.

6. Blisters that were cut open for sampling and inspection were dry or had a few droplets of water. In all cases, the cut piece was easily removed with a screwdriver indicating that little or no bond was present. Bonding, however, was good along the perimeter of the blisters. In areas containing pavement reinforcing fabric, the fabric was either not bonded or could easily be peeled off the bottom of the overlay or substrate.

7. The thermodynamic analysis of the blister gas behavior showed that the differential pressure that causes the blistering is due to the combined expansion effect of the contained gas and water vapor.

8. The finite element analysis simulating the behavior of blister 1 resulted in the calculation of pressures that were higher than those obtained in the thermodynamic analysis. The difference in the calculated pressures can be explained by the following reasons: (1) the finite element program treats the asphalt overlay as a homogeneous material (it is not), (2) cracks are present in the blistered overlay which reduces the bending stiffness, (3) the actual temperature could be several degrees higher than that measured because of the insulating effect of the trapped gases (i.e., the subsurface layers act as a heat sink), and (4) the initial starting point of 80°F used in the thermodynamic analysis may be higher than actual field conditions.

9. The results of the finite element analysis, assuming that a 2-inch overlay is placed directly over the existing pavement, indicates that blistering is still a possibility even with the additional overlay.

CONCLUSIONS

Based on field measurements and observations, laboratory test results, and analytical findings, we have concluded that the blistering occurs because:

1. Water and air enter through cracks caused by shrinkage of the overlay during the cold season.

2. The cracks heal during the warm season as a result of softening of the asphalt cement and the stresses created by the expansion of the pavement matrix itself thereby causing air and moisture to be trapped at the overlay substrate interface.

3. The effects of the diurnal changes in temperatures on the trapped air and water vapor are manifested in the diurnal growth and recession of the blisters.

4. The blistering occurs at locations where bonding of the overlay is deficient.

RECOMMENDATIONS

The three alternatives available relative to the present overlay are: (1) do nothing, (2) add another overlay, or (3) remove and replace the overlay. We recommend that alternative (3) be pursued because if properly installed, the possibility of blisters forming will be eliminated. In alternative (1), blisters will continue to form and the possibility of FOD to aircraft engines due to pavement fragments from the breakup of the blisters exists. We do not recommend alternative (2) because the probability of blisters forming exists because air and water can be trapped in void spaces of the present debonded areas at the time the new overlay is applied. Also, with time the same cracking, healing, and blistering phenomena as now exists could occur with the new overlay, because debonded areas exist under the present overlay.

ACKNOWLEDGMENT

The following NCEL scientists and engineers provided information and consultation that are reflected in this report: Dr. Eugene Cooper, Dr. Thomas O'Neill, David Pendleton, and Daniel Zarate.

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Table 1. Overlay Construction History
(After: Reference 1)

Item	Date
Contract awarded for construction	26 Sept 1980
Began construction	20 Oct 1980
Cold milling completed	30 Oct 1980
Single bituminous surface treatment interlayer installation completed	13 Nov 1980
Overlay work suspended due to cold weather	19 Dec 1980
Resumed overlay work	6 Apr 1981
Pavement reinforcing fabric interlayer installation completed	22 Apr 1981
Pavement overlay completed	24 Apr 1981

Table 2. Locations Where Field Measurements and Overlay Samplings Were Made on Runway 14-32

Item	Station	From Centerline
Temperature measurements Site No. 1	16+74	39 ft right
Blister No. 1	16+60	28 ft right
AC overlay sample No. 1	Same as blister No. 1	---
Blister No. 2	15+71	28 ft right
Temperature measurements Sute No. 2	46+51	59 ft right
Blister No. 3	46+56	49 ft right
AC overlay sample No. 3	Same as blister No. 3	---
Blister No. 4	46+08	9 ft left

Table 3. Locations and Ambient Conditions for Blister Gas Samples Taken on 11 Sep 1985

Sample No.	Station	From Runway Centerline	Time	Surface Temperature (°F)	Air Temperature (°F)
1	44+40	40 ft right	1230	114.9	89.6
2	44+75	40 ft right	1300	121.2	91.5
3	44+40	70 ft right	1320	128.5	93.4
4	20+00	Centerline	1410	134.6	95.4

Table 4. Blister Volume Changes

Blister No.	Date	Time	Volume (in.^{3})	Temperature, °F				
				Surface	1/2 in.	1 in.	1-1/2 in.	1 in.
1	8/27/85	1730	425	102.0				
	8/28/85	0933	0	80.0				
	8/28/85	1042		86.7	87.8	87.2	86.7	86.4
	8/28/85	1149	0	99.0				
	8/28/85	1434	154	106.6	108.6	107.1	106.0	105.3
	8/28/85	1708	196	101.1	104.1	104.2	104.6	104.9
2	8/27/85	1745	296	98.0				
	8/28/85	0945	0	81.0				
	8/28/85	1016		84.3	85.3	84.7	84.3	84.1
	8/28/85	1200	55	104.0				
	8/28/85	1434	147	106.6	108.6	107.1	106.0	105.3
	8/28/85	1717	151	99.7	102.7	103.0	103.5	103.8
3	8/28/85	1310	51					
	8/28/85	1345		105.0	106.0	105.0	104.0	103.0
	8/28/85	1626	91					
	8/28/85	1630		103.0	106.0	106.0	106.0	105.0
4	8/28/85	1321	4					
	8/28/85	1345		105.0	106.0	105.0	104.0	103.0
	8/28/85	1630		103.0	106.0	106.0	106.0	105.0
	8/28/85	1640	91					

Table 5. Constitutive Properties of Asphalt Concrete Pavement Versus Temperature (From: Ref 6, 7, and 8)

Temperature (°F)	Modulus of Elasticity (x10 psi)	Poisson's Ratio
80	0.30	0.41
100	0.15	0.44
120	0.09	0.46
140	0.07	0.47

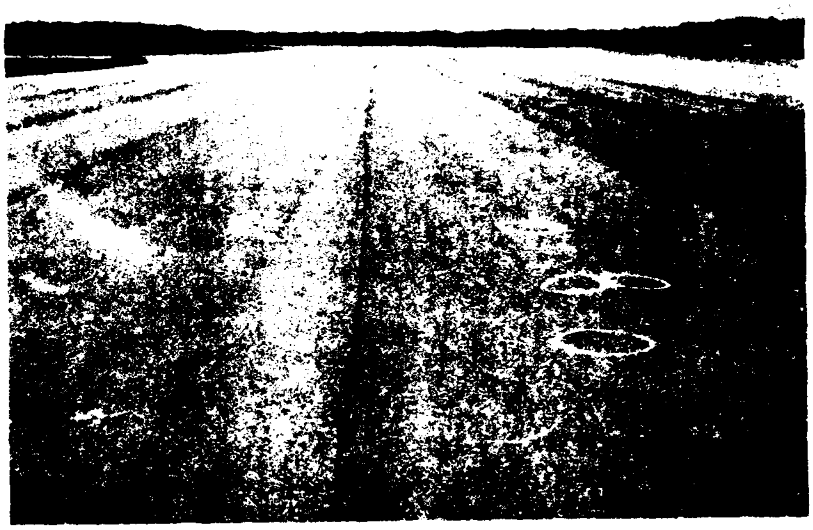


Figure 1. Overall view showing blisters (marked with paint) concentrated within paving lanes.

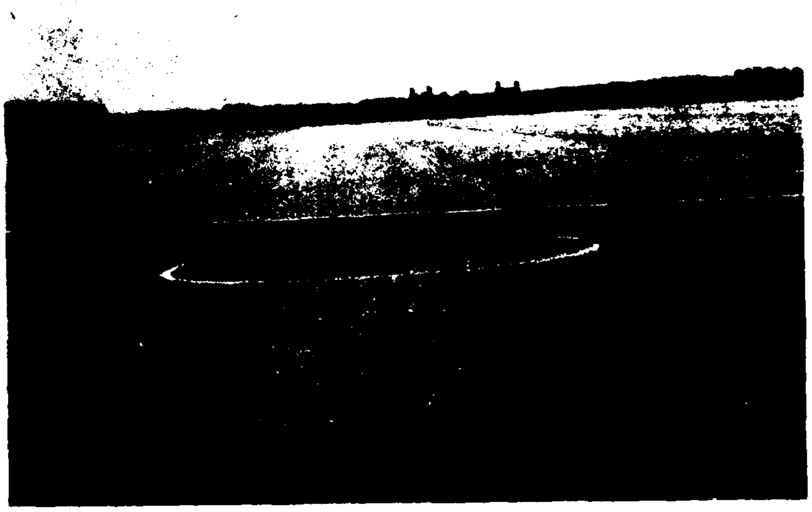


Figure 2. Example of a blister.

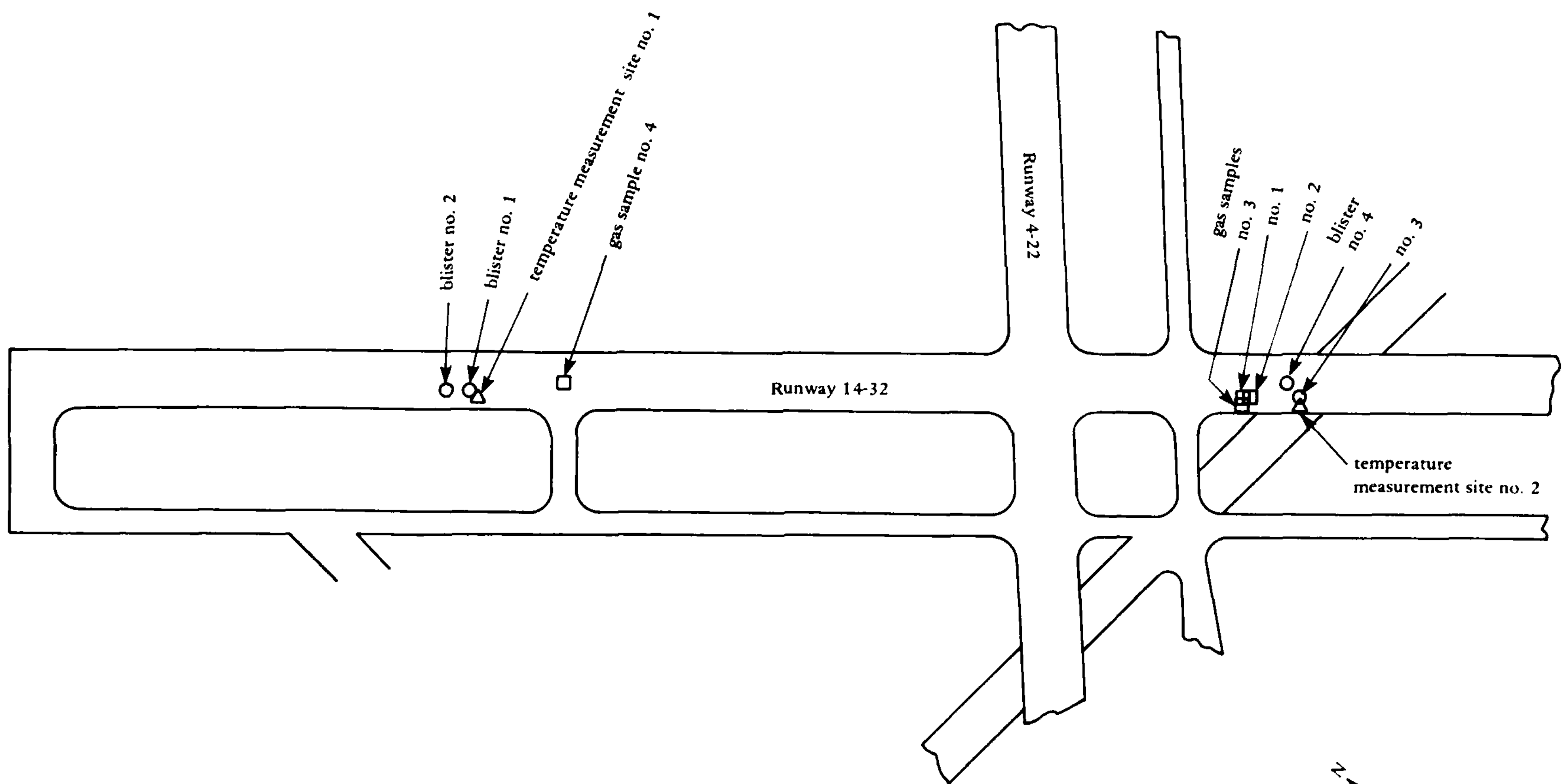


Figure 3. Locations on Runway 14-32 where temperature and blister behavior measurements were made and where gas and AC overlay samples were taken.

Figure 4. Thermocouple assembly used to measure pavement temperature profiles to a depth of 24 inches.

Figure 5. Epoxy adhesive grout mixed with sand used to install the thermocouple assemblies.

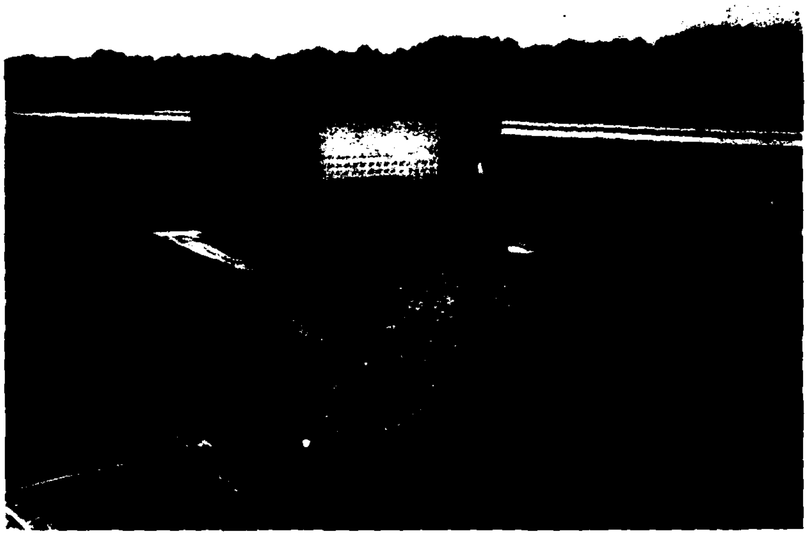


Figure 6. Digistrip III Datalogger used to record pavement temperatures.

Figure 7. Fluke, Inc. 10-channel digital thermometer used to take some of the measurements at blisters 3 and 4.

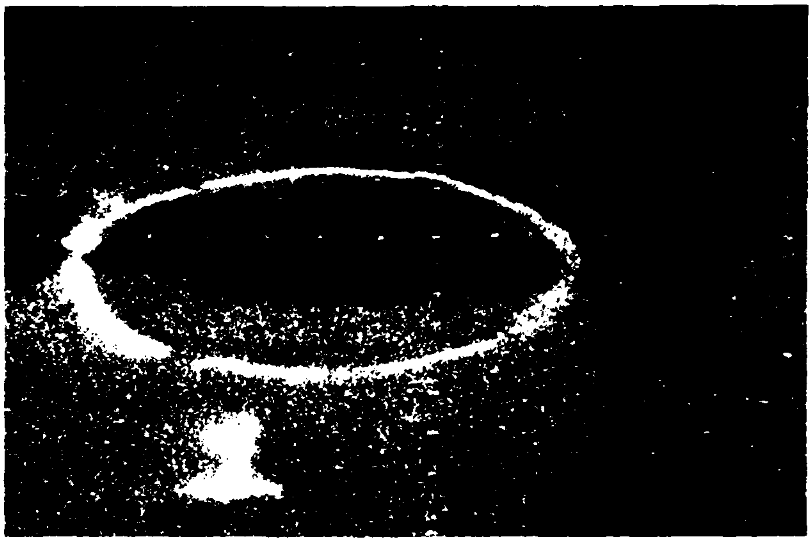


Figure 8. Typical blister deliniations (lines and points) where elevation readings were taken.

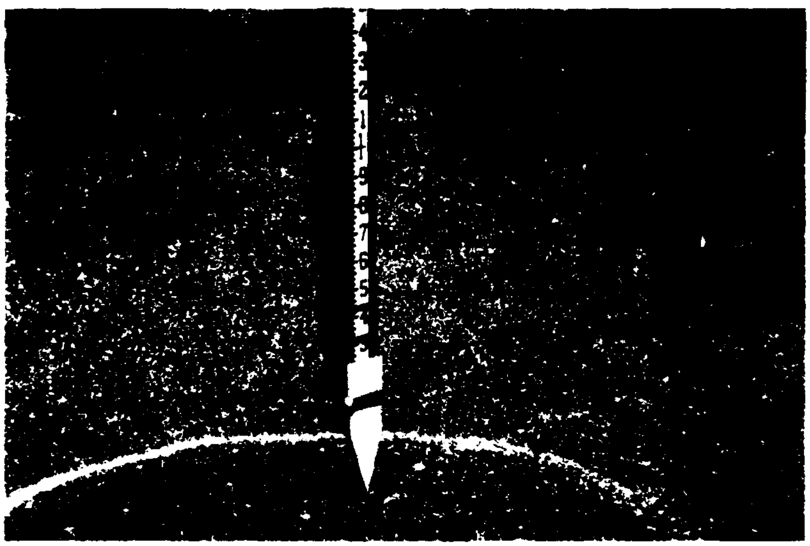


Figure 9. Level rod with modified base that was used for elevation measurements.

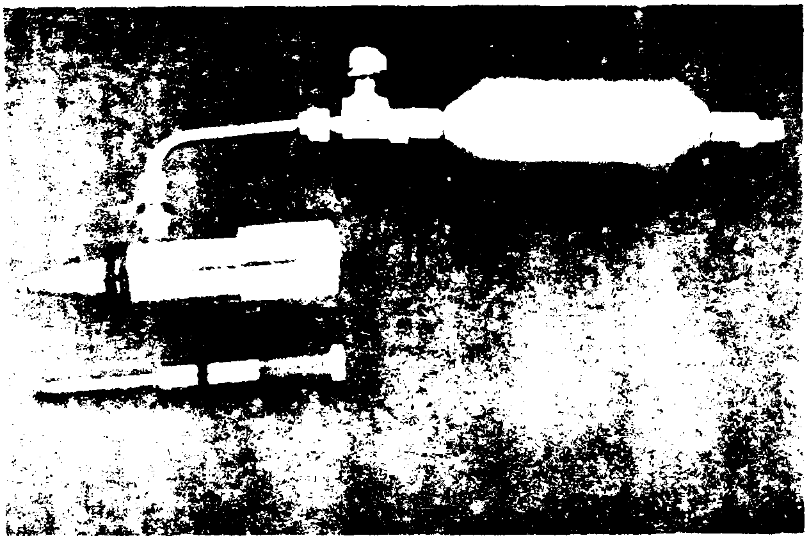


Figure 10. Gas extractor shown with the needle valve removed from the probe.

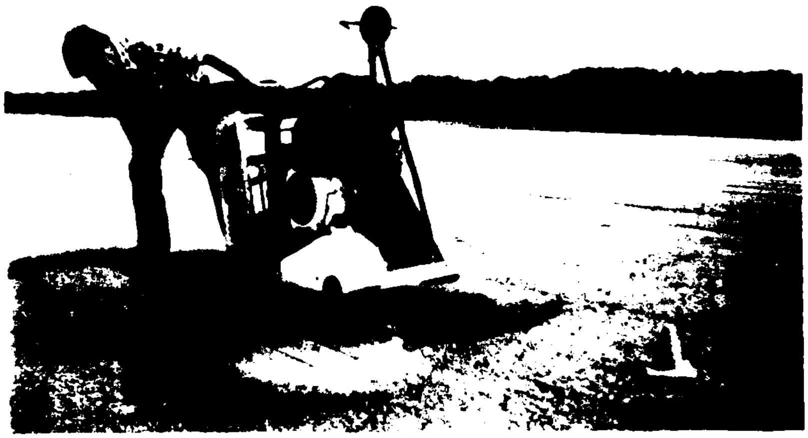


Figure 11. Saw cutting equipment used for taking samples of the AC overlay and for opening up the other blisters.

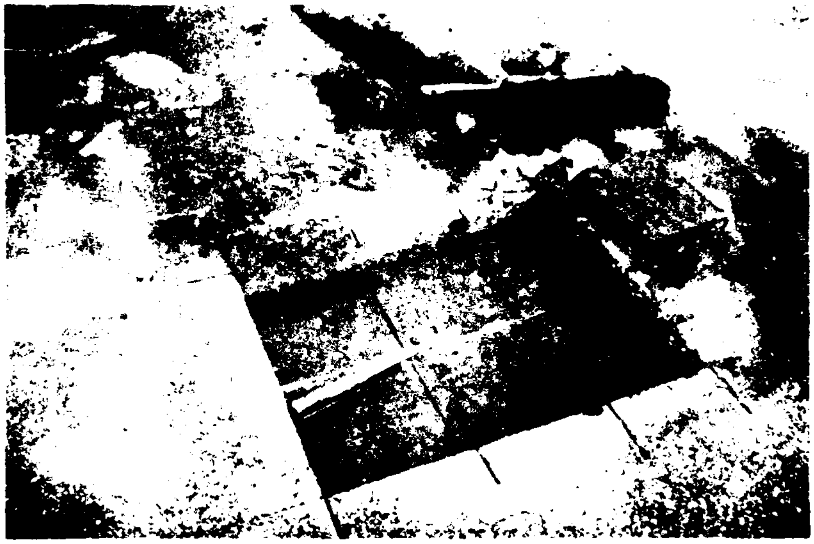


Figure 12. View of the hole at blister 3 after the AC overlay samples were removed showing the lack of bond between the overlay and substrate with the pavement reinforcing fabric.

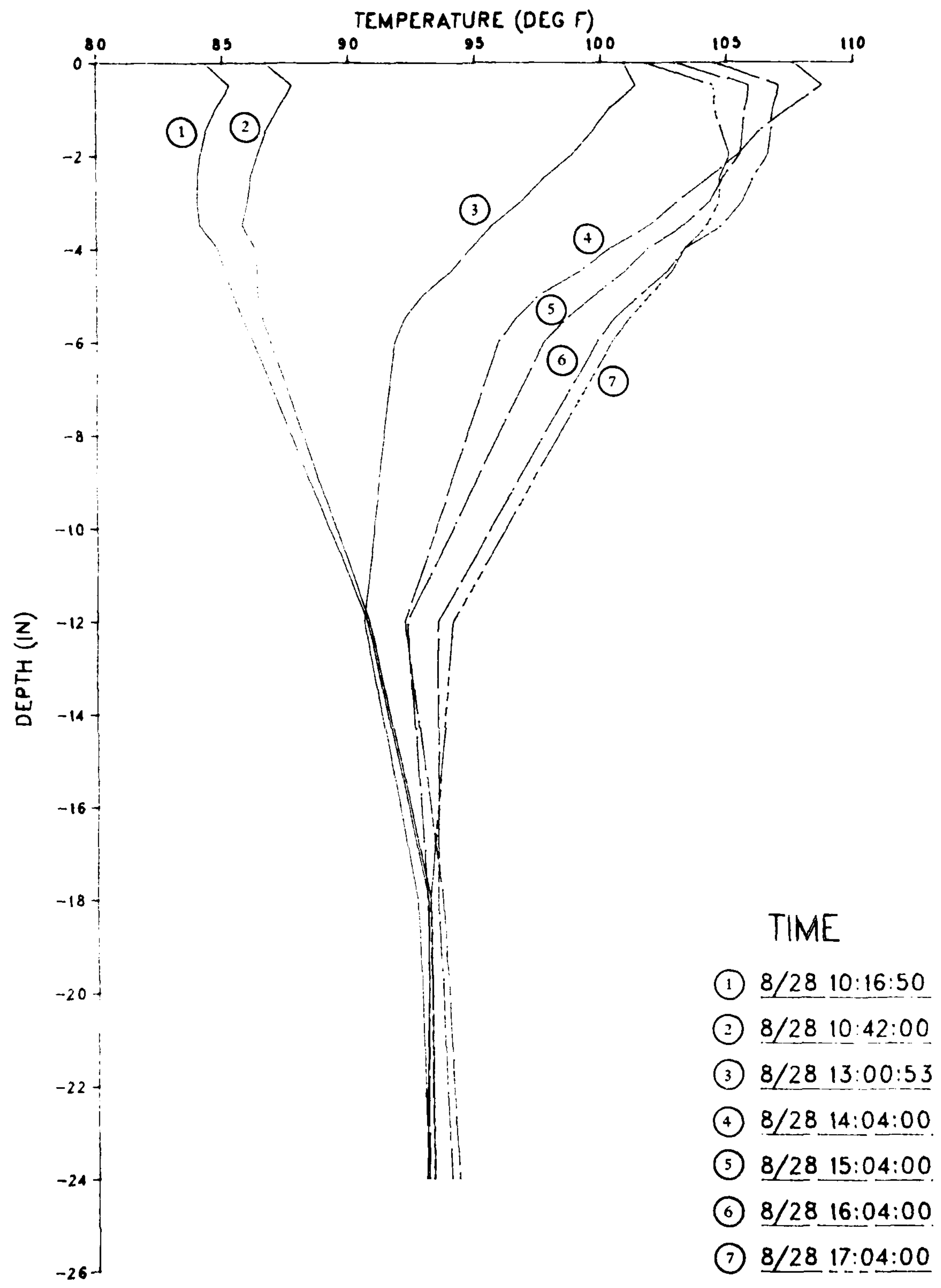


Figure 13. Temperature profiles at Site 1 near blisters 1 and 2.

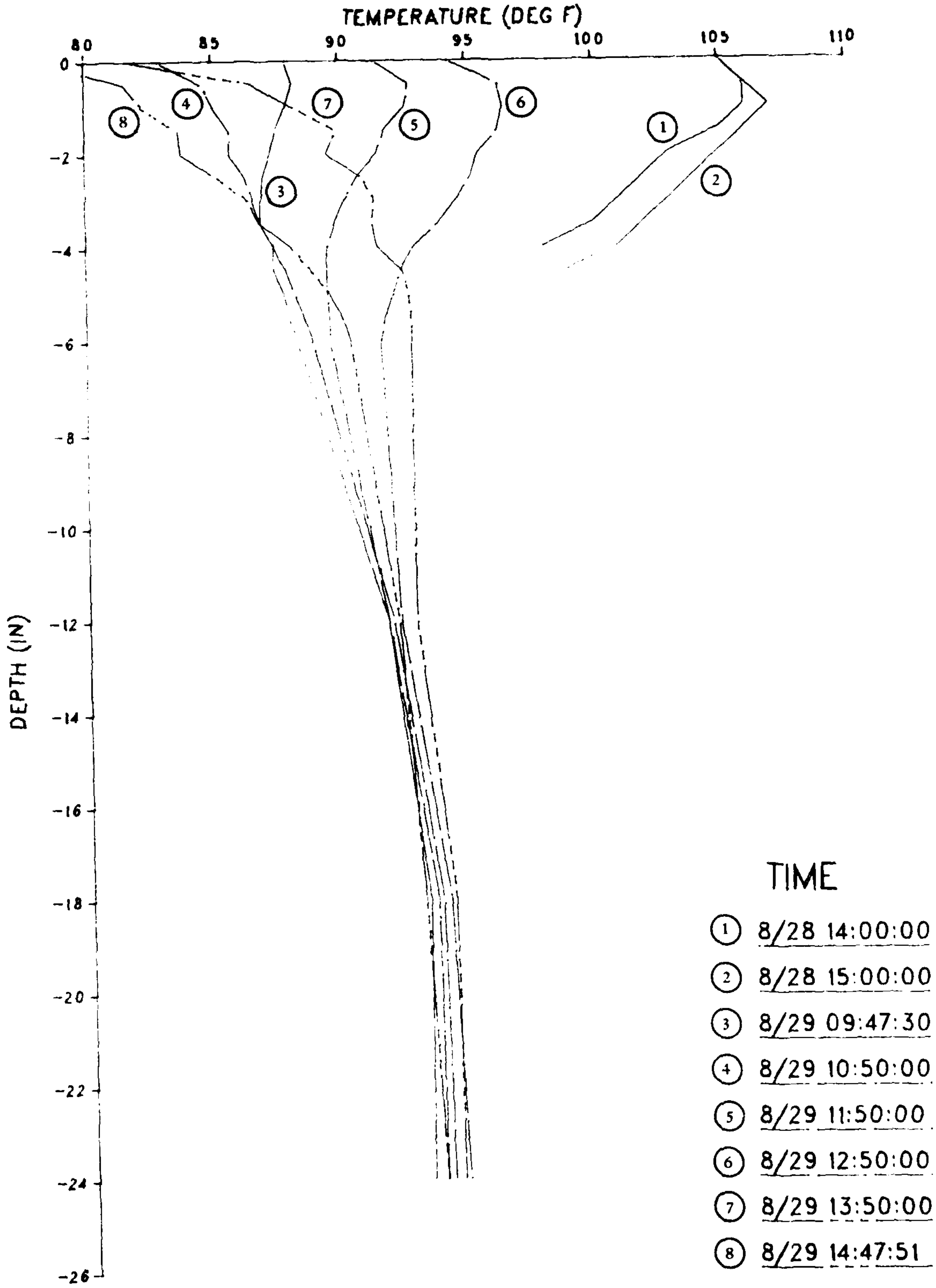
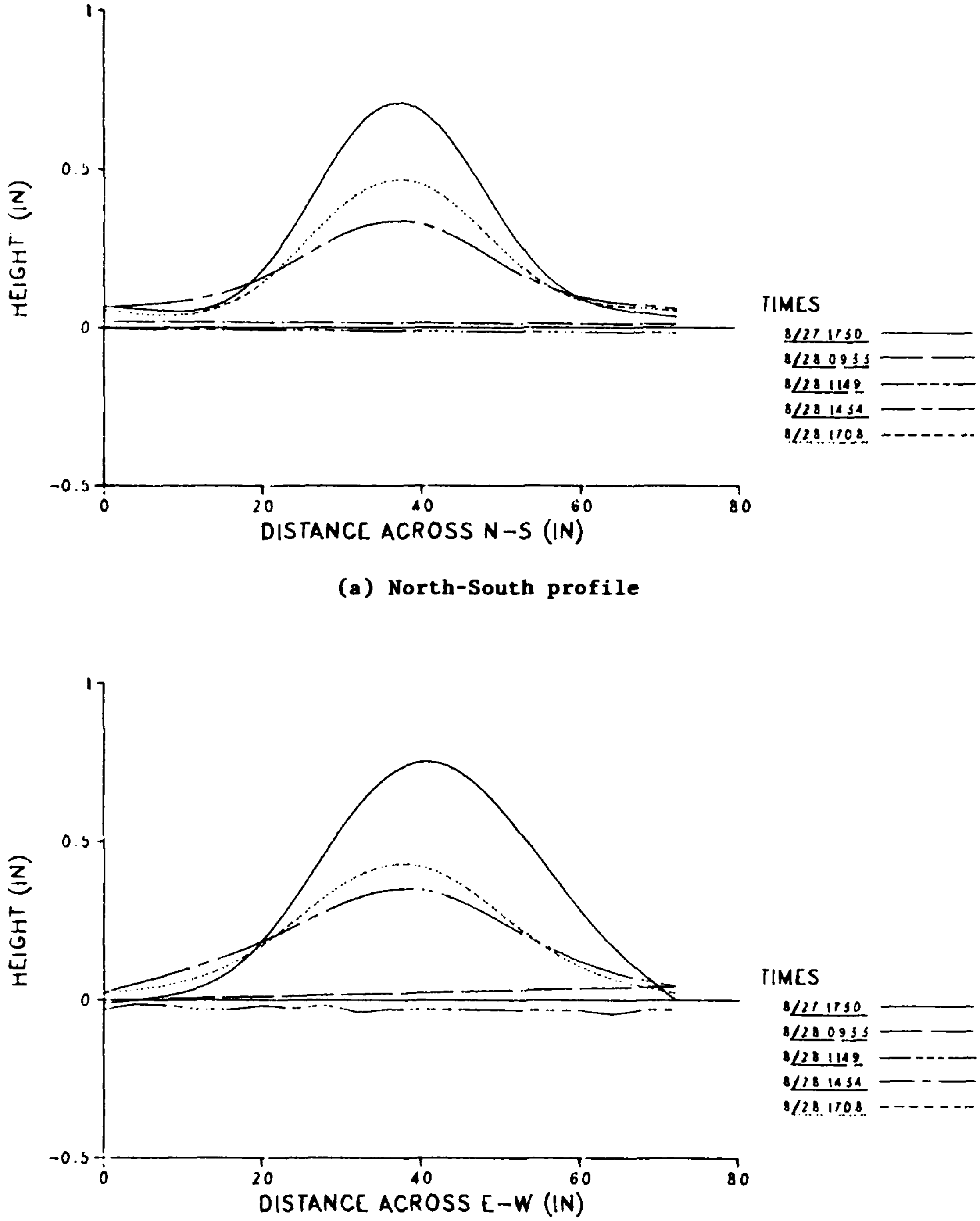


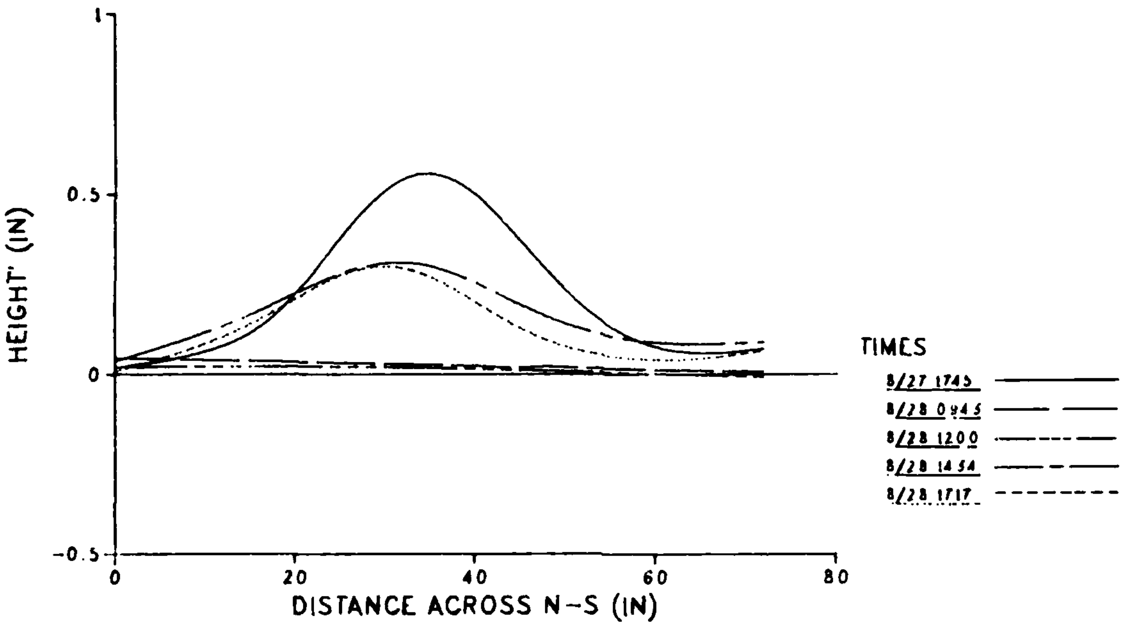
Figure 14. Temperature profiles at Site 2 near blisters 3 and 4.



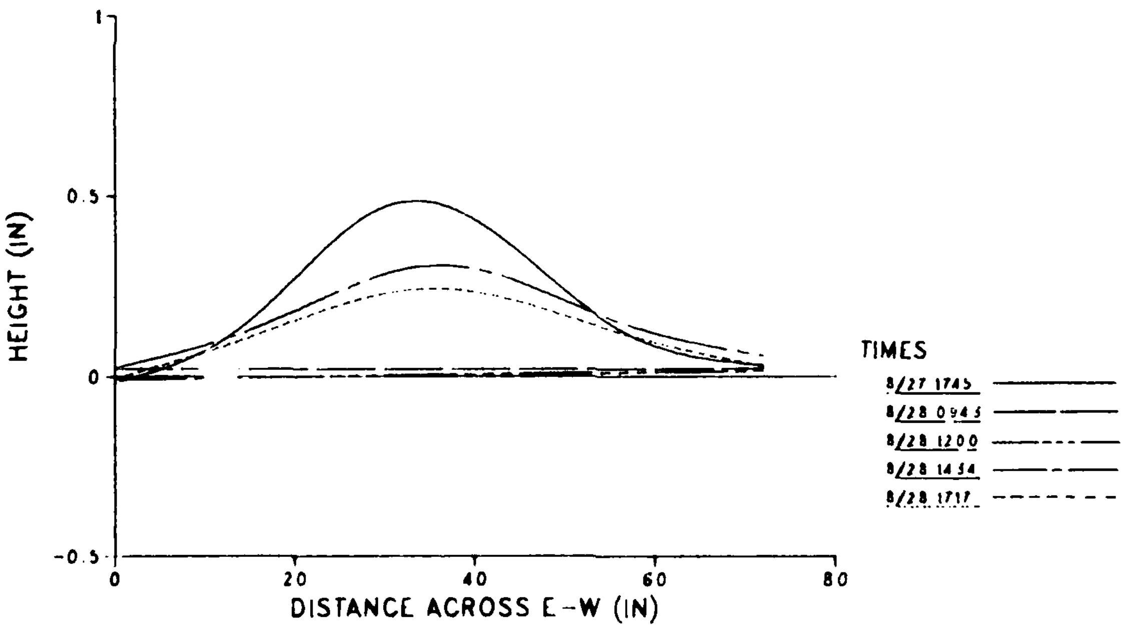
(a) North-South profile

(b) East-West profile

Figure 15. Profile changes of blister 1.

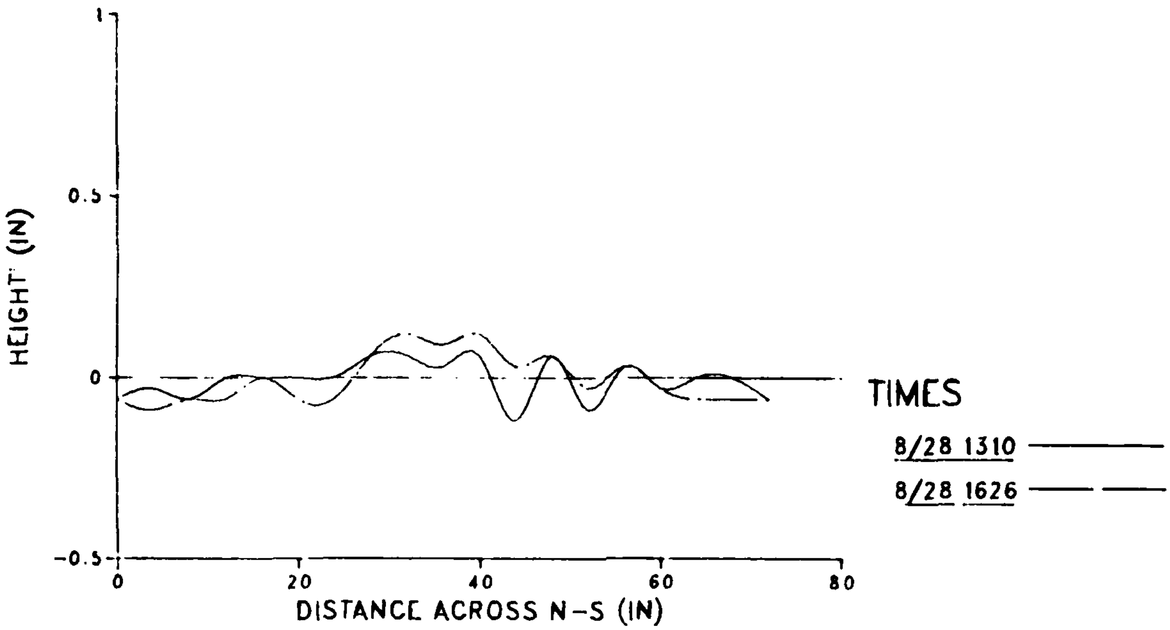


(a) North-South profile

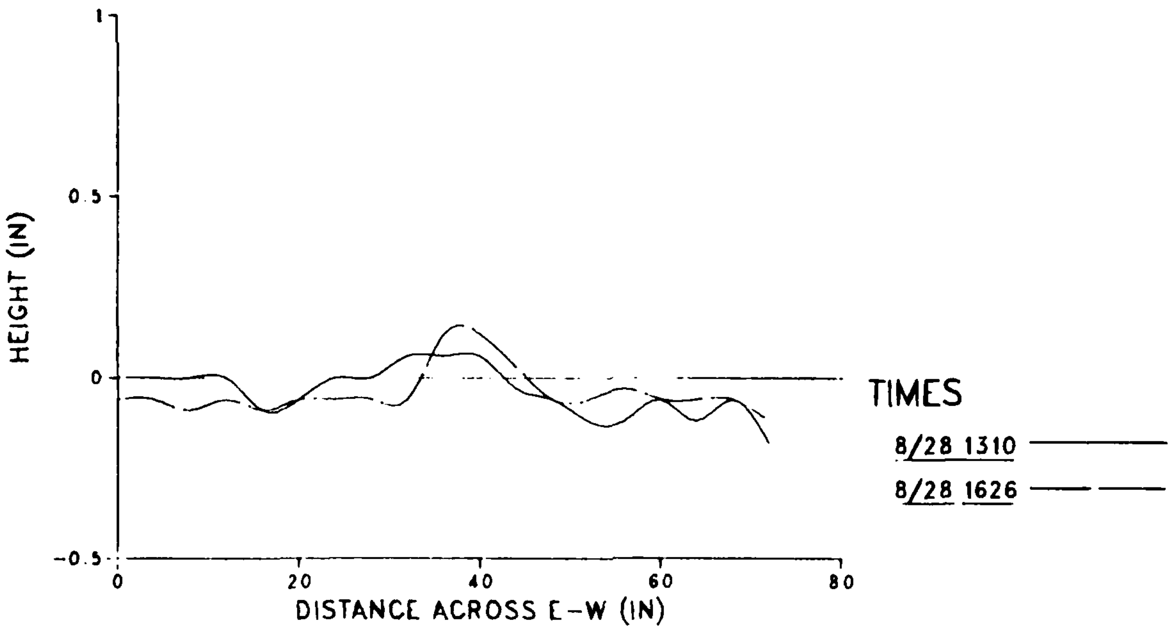


(b) East-West profile

Figure 16. Profile changes of blister 2.

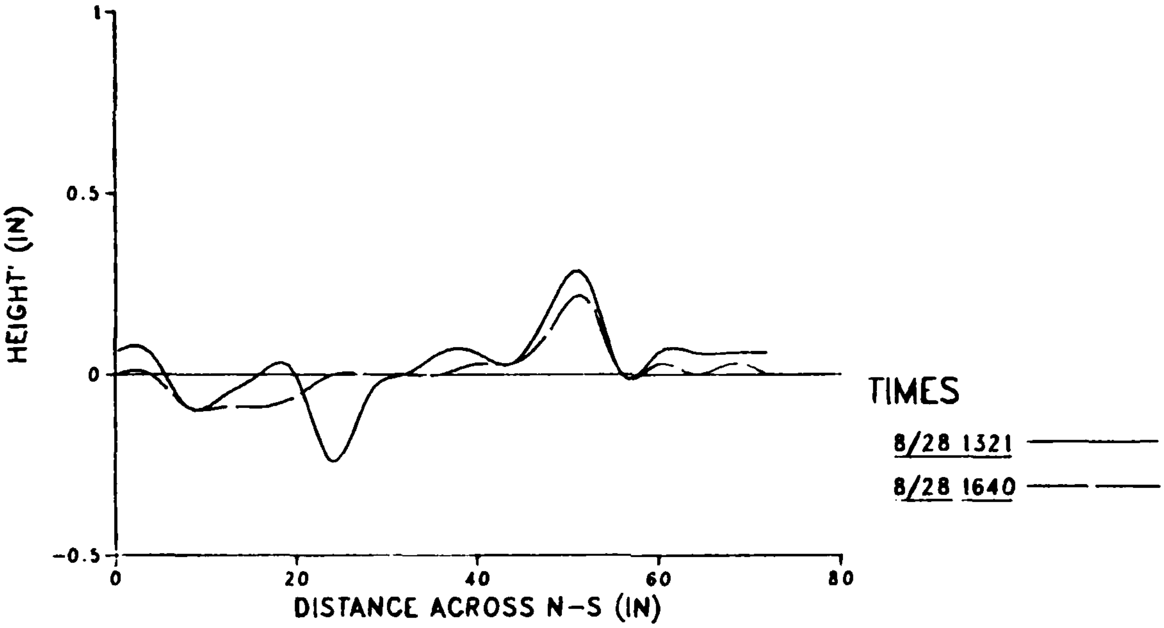


(a) North-South profile

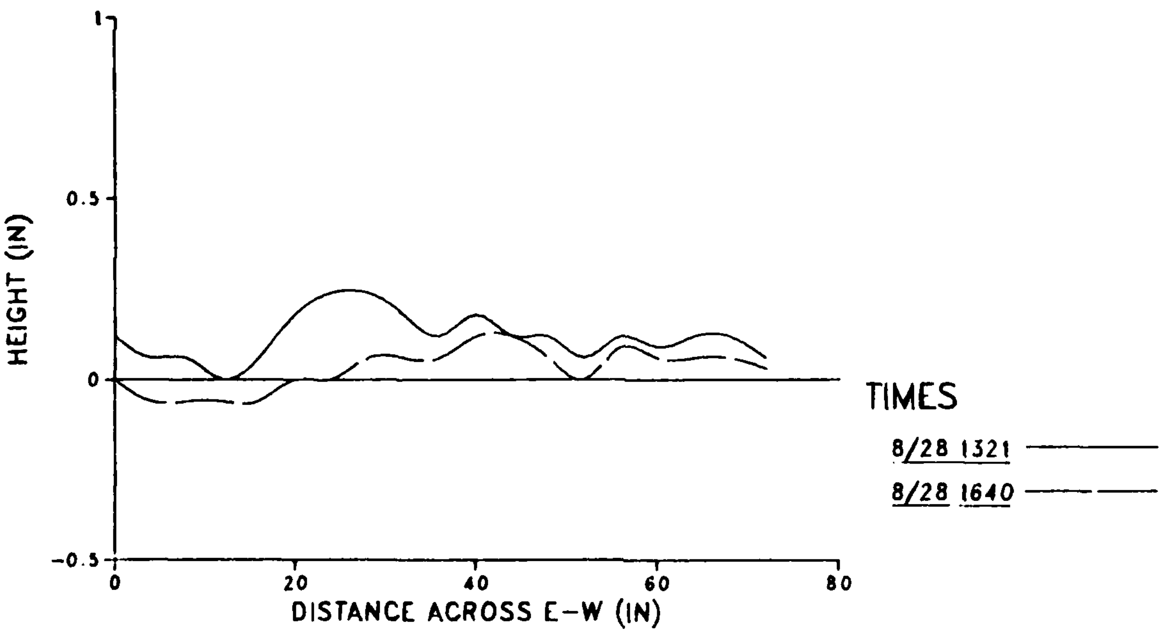


(b) East-West profile

Figure 17. Profile changes of blister 3.



(a) North-South profile



(b) East-West profile

Figure 18. Profile changes of blister 4.

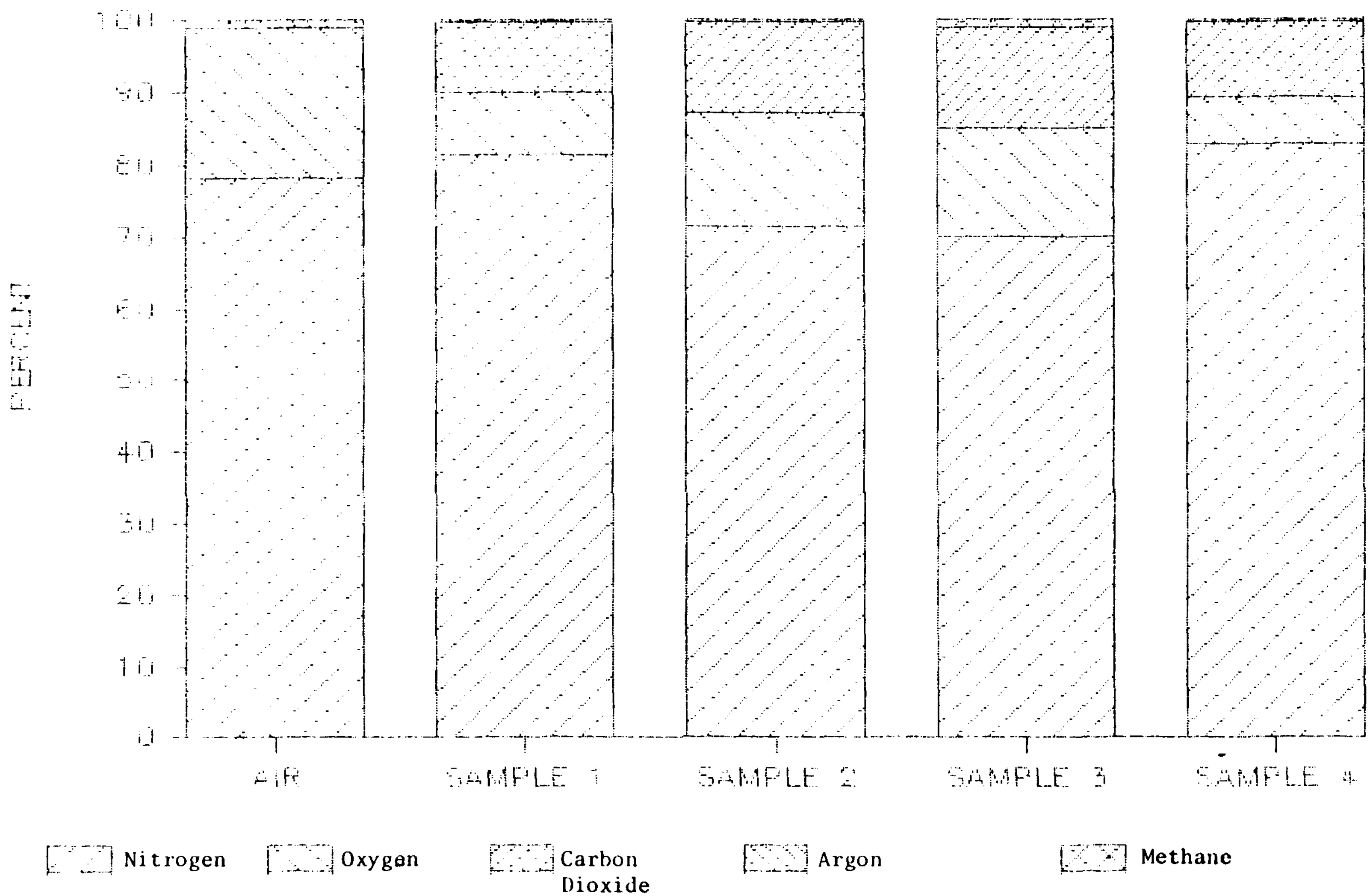


Figure 19. Composition of air compared to measured values from gas samples.

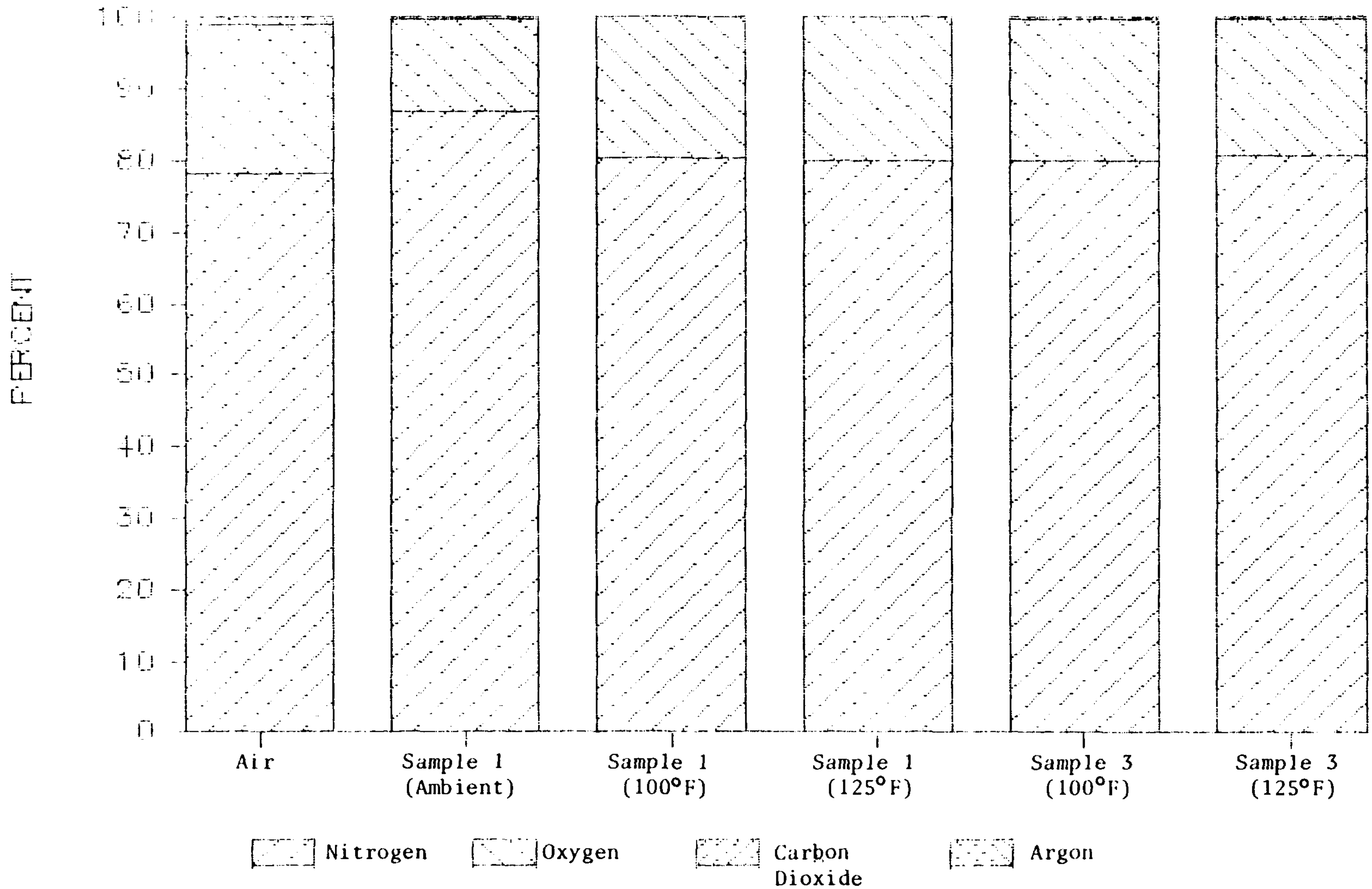


Figure 20. Composition of air compared to measured emitted gas from asphalt pavement samples at various temperature conditions.

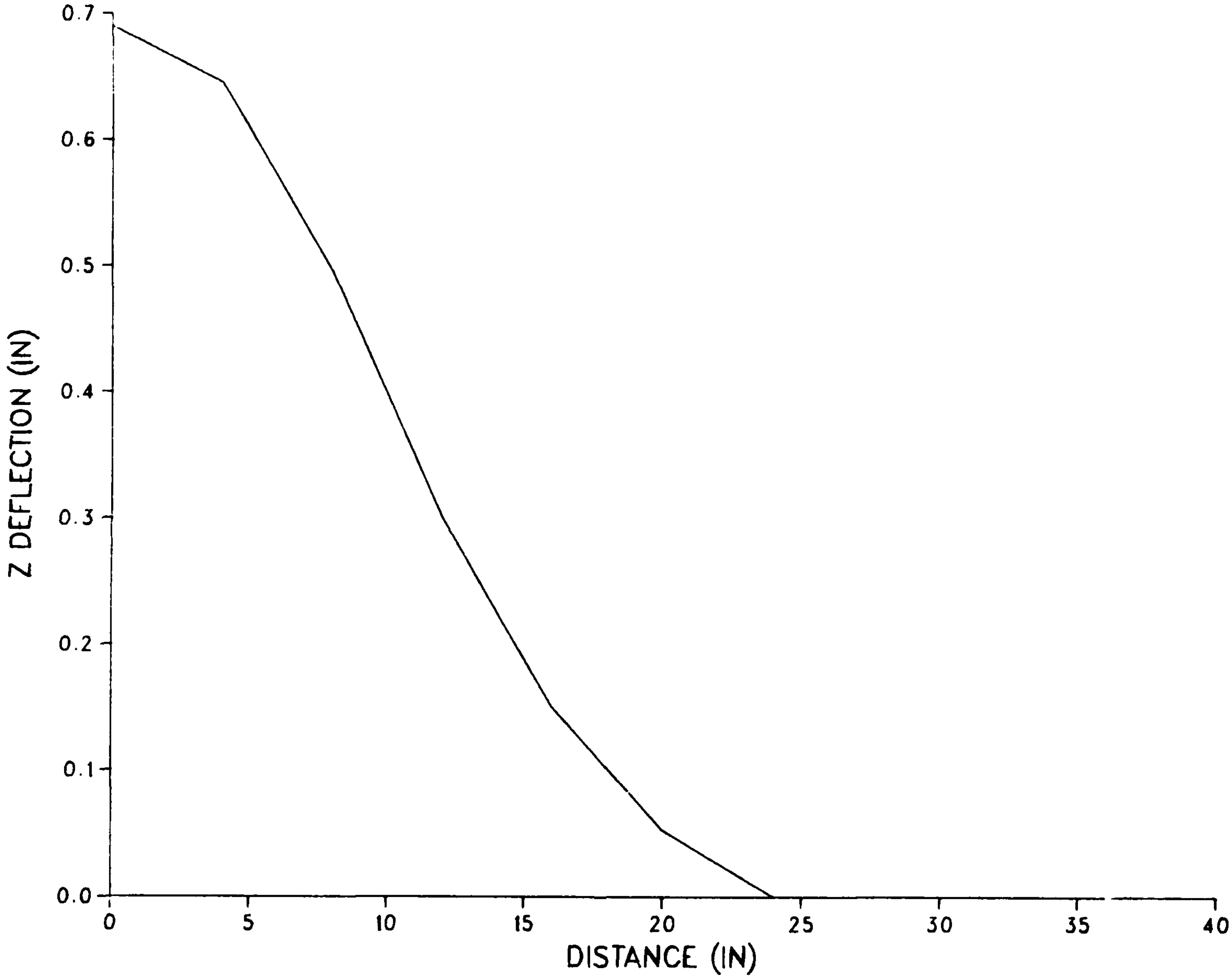


Figure 21. Average half profile of the surface of blister 1.

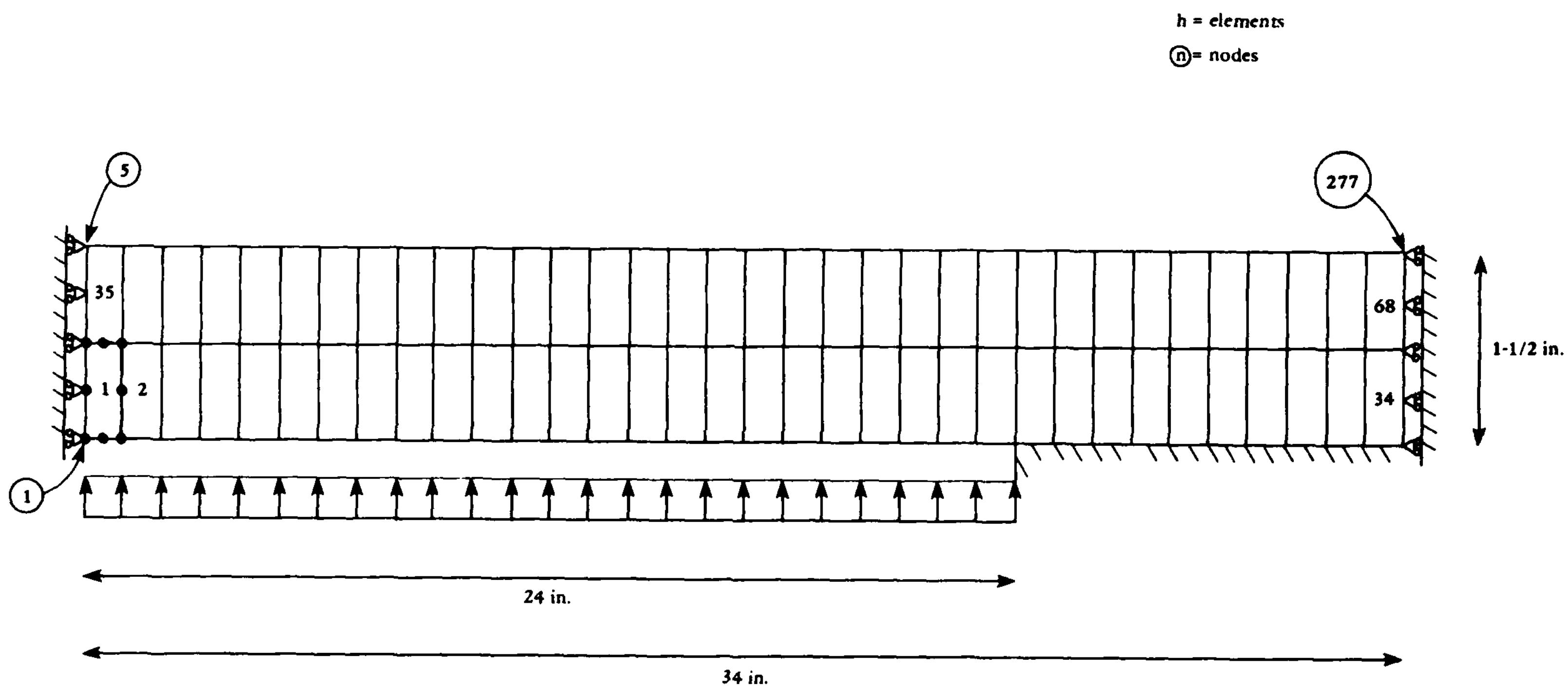


Figure 22. Finite element mesh used to simulate the characteristics of blister 1.

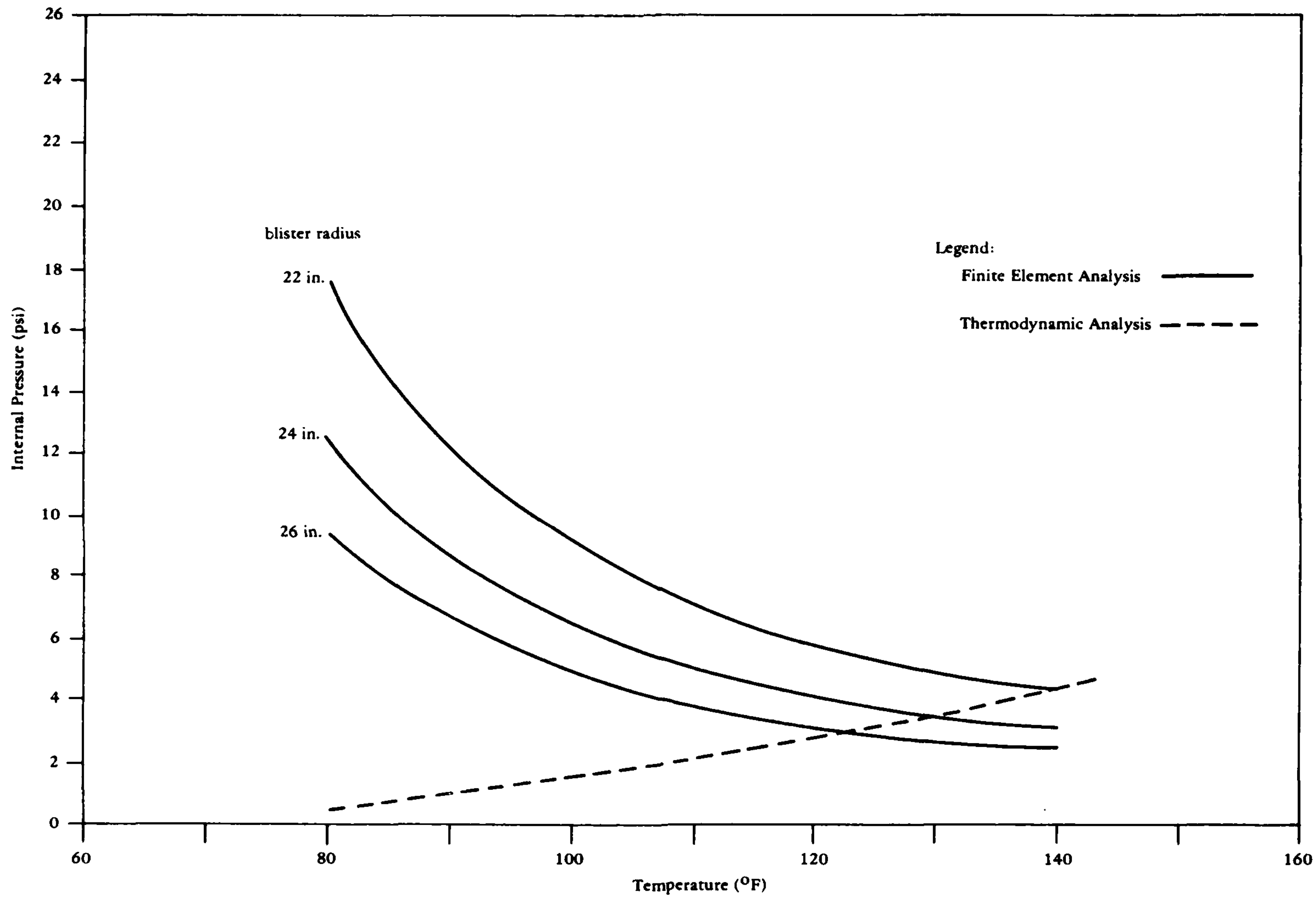


Figure 23. Internal pressures required for a crown deflection of 0.69 inch for various size blisters computed by the finite element method compared to pressures computed in the thermodynamic analysis of blister gases and water vapor.

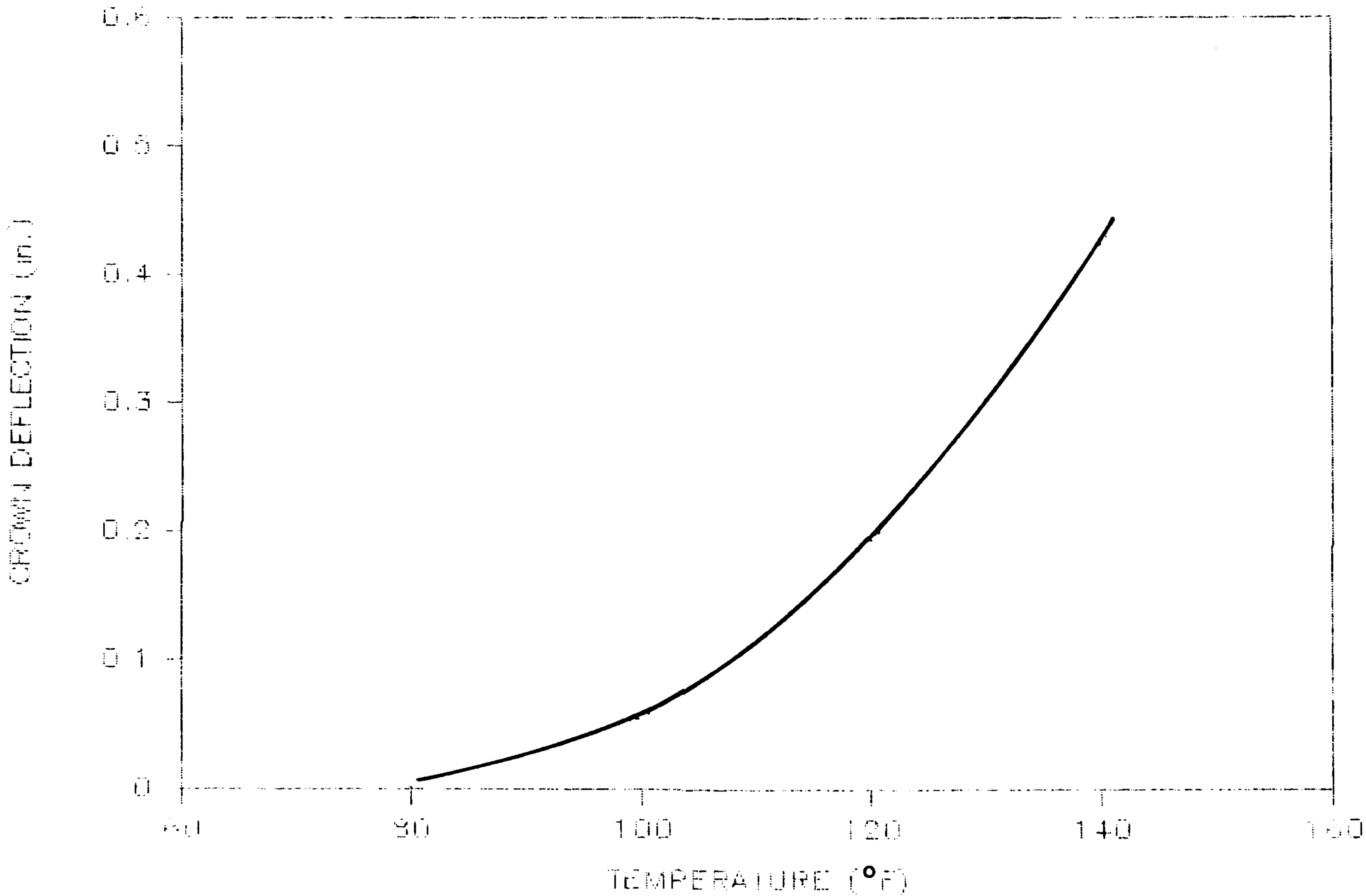


Figure 24. Crown deflections at various temperatures for a 24-inch radius blister in a new 2-inch thick overlay over the existing pavement.

Appendix A

PAVEMENT TEMPERATURE PROFILES

Table A-1. Pavement Temperature (°F) Measurements Near Blisters 1 and 2 on 28 Aug 1985

Depth (in.)	Time (hr:min:sec)					
	10:16:50	10:17:10	10:17:30	10:17:50	10:18:09	10:26:36
0.0	84.3	84.5	84.5	84.6	84.6	85.7
0.5	85.3	85.4	85.4	85.5	85.6	86.6
1.0	84.7	84.9	84.8	84.9	85.0	86.0
1.5	84.3	84.5	84.5	84.5	84.6	85.5
2.0	84.1	84.3	84.2	84.2	84.3	85.2
2.5	84.0	84.1	84.1	84.1	84.2	85.0
3.0	84.0	84.1	84.1	84.0	84.1	84.8
3.5	84.1	84.1	84.1	84.1	84.2	84.8
4.0	84.8	84.9	84.8	84.8	84.9	85.4
4.5	85.1	85.1	85.1	85.1	85.0	85.5
5.0	85.4	85.4	85.5	85.4	85.4	85.7
5.5	85.8	85.8	85.8	85.8	85.8	86.1
6.0	86.2	86.1	86.2	86.2	86.2	86.4
12.0	90.7	90.7	90.8	90.7	90.8	90.7
18.0	93.1	93.1	93.1	93.0	93.1	93.0
24.0	93.0	93.1	93.1	93.0	93.1	93.1

Depth (in.)	Time (hr:min:sec)					
	10:27:00	10:42:00	13:00:53	13:03:51	13:19:00	13:34:00
0.0	85.9	86.7	100.9	100.3	104.2	105.0
0.5	86.7	87.8	101.4	101.3	104.9	106.4
1.0	86.0	87.2	100.3	100.2	103.3	104.9
1.5	85.6	86.7	99.6	99.4	102.2	103.9
2.0	85.3	86.4	98.8	98.6	101.0	102.8
2.5	85.0	86.1	97.7	97.5	99.7	101.6
3.0	84.9	86.0	96.8	96.6	98.4	100.2
3.5	84.8	85.8	95.7	95.5	97.0	98.8
4.0	85.4	86.3	94.8	94.5	96.1	97.5
4.5	85.6	86.4	94.0	93.7	95.1	96.5
5.0	85.8	86.4	92.9	92.6	93.8	95.1
5.5	86.0	86.6	92.2	91.9	92.9	94.1
6.0	86.4	86.9	91.8	91.5	92.4	93.5
12.0	90.7	90.8	90.6	90.2	90.4	91.1
18.0	93.0	93.2	92.7	92.3	92.4	92.8
24.0	93.0	93.3	93.1	92.7	92.7	93.1

(continued)

Table A-1. Continued

Date (in.)	Time (hr:min:sec)					
	13:49:00	14:04:00	14:19:00	14:34:00	14:49:00	15:04:00
0.0	104.5	107.6	105.3	106.6	105.9	102.9
0.5	106.6	108.8	108.0	108.6	108.7	105.9
1.0	105.4	107.4	107.1	107.1	107.7	105.7
1.5	104.7	106.2	106.4	106.0	106.9	105.6
2.0	103.9	105.4	105.7	105.3	106.5	105.5
2.5	102.7	104.2	104.5	104.3	105.5	104.8
3.0	101.4	103.0	103.4	103.1	104.6	104.3
3.5	100.0	101.9	102.0	101.5	103.3	103.3
4.0	98.5	100.3	100.2	101.1	101.8	101.8
4.5	97.5	99.1	99.1	100.2	100.9	100.9
5.0	96.0	97.5	97.7	98.9	99.4	99.7
5.5	95.0	96.6	96.5	97.7	98.4	98.6
6.0	94.5	95.9	95.8	97.1	97.7	97.7
12.0	91.4	92.2	91.5	92.3	92.5	92.3
18.0	93.1	93.7	92.9	93.3	93.6	93.1
24.0	93.5	94.3	93.4	93.4	94.0	93.0

Date (in.)	Time (hr:min:sec)					
	15:19:00	15:34:00	15:49:00	16:04:00	16:19:00	16:34:00
0.0	103.7	104.7	105.1	104.5	102.4	102.7
0.5	106.4	107.3	107.4	107.1	104.9	105.2
1.0	105.9	106.6	106.8	106.8	105.0	105.2
1.5	105.6	106.3	106.3	106.7	105.2	105.3
2.0	105.6	106.1	106.2	106.6	105.5	105.6
2.5	104.9	105.3	105.4	106.0	105.0	105.2
3.0	104.5	104.8	105.0	105.6	105.0	105.1
3.5	103.6	103.8	104.2	104.8	104.4	104.5
4.0	101.9	102.3	102.7	103.3	103.1	103.3
4.5	101.1	101.6	101.9	102.6	102.7	102.9
5.0	100.1	100.4	100.8	101.5	101.6	101.9
5.5	99.0	99.3	99.8	100.5	100.6	100.9
6.0	98.3	98.6	99.1	99.8	99.9	100.2
12.0	92.6	92.5	92.9	93.5	93.8	94.0
18.0	93.2	92.9	93.1	93.5	93.6	93.5
24.0	93.6	93.4	93.6	94.0	94.0	93.8

(continued)

Table A-1. Continued

Date (in.)	Time (hr:min:sec)					
	16:49:00	17:04:00	17:08:00	17:18:00	17:20:00	17:28:29
0.0	102.9	101.8	101.1	99.7	99.4	99.1
0.5	105.3	104.5	104.1	102.7	102.6	101.9
1.0	105.1	104.5	104.2	103.0	102.9	102.2
1.5	105.1	104.8	104.6	103.5	103.4	102.7
2.0	105.3	105.1	104.9	103.8	103.8	103.1
2.5	104.8	104.7	104.5	103.6	103.6	102.8
3.0	104.7	104.7	104.6	103.8	103.9	103.1
3.5	104.0	104.2	104.2	103.6	103.7	102.9
4.0	103.1	103.3	103.5	103.0	103.0	102.7
4.5	102.7	102.8	103.1	102.6	102.7	102.3
5.0	101.7	101.9	102.2	101.9	102.0	101.7
5.5	100.8	101.1	101.4	101.2	101.3	101.1
6.0	100.1	100.4	100.8	100.6	100.7	100.5
12.0	93.9	94.1	94.7	94.6	94.8	94.6
18.0	93.1	93.2	93.7	93.6	93.7	93.4
24.0	93.2	93.3	93.8	93.6	93.8	93.3

Table A-2. Pavement Temperature (°F) Measurements Near Blisters 3 and 4 on 28 Aug 1984

Date (in.)	Time (hr:min:sec)					
	13:45:00	14:00:00	14:15:00	14:30:00	14:45:00	15:0:00
0.0	105.0	105.0	106.0	107.0	106.0	105.0
0.5	106.0	106.0	107.0	108.0	107.0	106.0
1.0	105.0	106.0	107.0	107.0	106.0	107.0
1.5	104.0	105.0	106.0	106.0	106.0	106.0
2.0	103.0	103.0	104.0	105.0	105.0	105.0
2.5	101.0	102.0	103.0	104.0	104.0	104.0
3.0	100.0	101.0	102.0	102.0	103.0	103.0
3.5	99.0	100.0	101.0	101.0	102.0	102.0
4.0	97.0	98.0	99.0	100.0	101.0	101.0
4.5					99.0	99.0
5.0						
5.5						
6.0						
12.0						
18.0						
24.0						

Depth (in.)	Time (hr:min:sec)	
	16:30:00	16:45:00
0.0	103.0	105.0
0.5	106.0	107.0
1.0	106.0	107.0
1.5	106.0	106.0
2.0	105.0	105.0
2.5	104.0	105.0
3.0	104.0	104.0
3.5	103.0	103.0
4.0	102.0	102.0
4.5	101.0	102.0
5.0		
5.5		
6.0		
12.0		
18.0		
24.0	90.0	90.0

Table A-3. Pavement Temperature (°F) Measurements Near Blisters 3 and 4 on 29 Aug 1985

Date (in.)	Time (hr:min:sec)					
	09:47:30	10:05:00	10:20:00	10:35:00	10:50:00	11:05:00
0.0	87.9	85.2	81.8	82.5	82.9	83.9
0.5	88.2	87.9	84.6	84.5	84.6	85.4
1.0	87.9	88.3	85.5	85.1	85.1	85.8
1.5	87.5	88.5	86.3	85.8	85.7	86.2
2.0	87.3	88.2	86.2	85.7	85.7	86.1
2.5	87.0	88.4	86.9	86.4	86.3	86.5
3.0	86.9	88.4	87.2	86.7	86.6	86.7
3.5	86.9	88.4	87.4	86.9	86.9	86.9
4.0	87.4	88.3	87.7	87.5	87.4	87.7
4.5	87.4	88.5	88.1	88.0	87.9	88.2
5.0	87.8	88.7	88.4	88.3	88.2	88.5
5.5	88.0	88.9	88.7	88.6	88.6	88.8
6.0	88.3	89.1	89.0	88.8	88.9	89.0
12.0	91.8	92.4	92.3	92.0	92.0	92.0
18.0	93.3	94.2	94.1	93.8	93.8	93.7
24.0	93.3	94.5	94.4	94.1	94.1	93.9

Date (in.)	Time (hr:min:sec)					
	11:14:48	11:15:09	11:20:00	11:35:00	11:43:21	11:50:00
0.0	84.7	84.7	86.3	90.7	91.4	91.4
0.5	85.6	85.6	86.8	90.5	92.2	92.8
1.0	85.8	85.8	86.9	90.0	92.0	92.6
1.5	86.1	86.2	86.9	89.3	90.9	91.8
2.0	86.2	86.2	86.9	89.2	90.7	91.5
2.5	86.5	86.5	87.1	88.7	90.1	90.7
3.0	86.7	86.8	87.2	88.5	89.5	90.2
3.5	86.8	86.9	87.3	88.4	89.3	89.8
4.0	87.4	87.5	87.9	88.5	89.3	89.5
4.5	87.9	88.0	88.4	88.6	89.2	89.5
5.0	88.2	88.3	88.7	88.7	89.2	89.5
5.5	88.6	88.6	89.0	89.0	89.5	89.6
6.0	88.8	88.8	89.2	89.0	89.4	89.6
12.0	91.7	91.8	91.9	91.6	91.7	91.8
18.0	93.5	93.5	93.7	93.4	93.6	93.6
24.0	93.6	93.7	93.9	93.7	93.9	93.8

(continued)

Table A-3. Continued

Date (in.)	Time (hr:min:sec)					
	12:05:00	12:20:00	12:35:00	12:50:00	12:05:00	13:20:00
0.0	91.5	96.4	97.1	94.3	92.4	89.3
0.5	92.4	95.6	98.5	96.3	94.8	92.8
1.0	92.4	94.8	98.1	96.5	95.2	93.4
1.5	92.2	93.8	97.1	96.3	95.4	93.9
2.0	91.8	93.4	96.2	95.5	94.7	93.2
2.5	91.5	92.6	95.3	95.2	94.7	93.5
3.0	91.1	92.1	94.6	94.6	94.4	93.3
3.5	90.7	91.6	93.8	93.9	93.9	93.0
4.0	90.2	90.9	92.6	92.9	93.0	93.0
4.5	90.0	90.7	92.1	92.4	92.7	93.0
5.0	89.9	90.5	91.8	92.1	92.4	92.7
5.5	90.0	90.4	91.6	91.8	92.1	92.4
6.0	89.9	90.3	91.3	91.6	91.9	92.1
12.0	91.9	91.9	92.5	92.3	92.3	92.2
18.0	93.7	93.7	94.3	94.1	94.1	93.8
24.0	94.2	94.2	95.0	94.7	94.8	94.3

Date (in.)	Time (hr:min:sec)				
	13:35:00	13:50:00	14:05:00	14:20:00	14:47:51
0.0	86.8	81.7	79.4	78.7	78.4
0.5	90.7	86.6	83.8	82.7	81.6
1.0	91.6	88.2	85.3	84.2	82.3
1.5	92.4	89.9	87.1	86.0	83.7
2.0	92.0	89.5	87.0	85.9	83.8
2.5	92.8	90.9	88.6	87.5	85.2
3.0	93.0	91.4	89.3	88.5	86.4
3.5	92.9	91.3	89.6	88.8	86.9
4.0	92.7	91.5	90.3	89.7	88.1
4.5	93.0	92.5	91.3	91.1	88.9
5.0	92.9	92.7	91.7	91.5	89.6
5.5	92.7	92.8	91.9	91.9	90.1
6.0	92.6	92.8	92.1	92.1	90.4
12.0	92.7	92.9	92.6	92.8	92.2
18.0	94.4	94.3	94.0	94.1	93.1
24.0	95.1	94.5	94.2	94.4	93.8

Appendix B

MCAS AMBIENT AIR TEMPERATURES

Table B-1. MCAS Ambient Air Temperatures and Precipitation Data

Date (1985)	Precipitation (in.)	Time	Temperature (°F)
Aug 1	1.05		
2	0.01		
3			
4			
5			
6	0.22		
7	1.69		
8	0.19		
9	0.01		
10			
11			
12			
13			
14			
15			
16			
17	0.73		
18			
19			
20			
21	0.27		
22			
23			
24			
25	0.75		
26			
27	0.03		
28		1000	78
		1100	80
		1200	84
		1300	86
		1400	87
		1500	88
		1600	87
		1700	87
		1800	85
		1900	84
	0.62	2000	82

(continued)

Table B-1. Continued

Date (1985)	Precipitation (in.)	Time	Temperature (°F)
Aug 29		0700	78
		0800	79
		0900	79
		1000	81
		1100	81
		1200	85
		1300	85
		1400	77
		1500	75
		1600	78
		1700	78
		1800	77
		1900	78
	0.13	2000	79
30		0700	76
		0800	76
		0900	77
		1000	80
		1100	82
	4.16	1200	84
31	Trace		
Total	9.86		

Appendix C

TEST RESULTS ON GAS SAMPLES

CHEMICAL RESEARCH LABORATORIES

LABORATORY REPORT

11631 SEABOARD CIRCLE (213) 598-0458
STANTON, CA 90680 (714) 898-6370

From: Jacobs Environmental Laboratories (CRL)
29 N. Olive Street
Ventura, CA 93001
ATTN: Mr. Thomas Mikel

Analysis No. V5993
Sampling Date 9/11/85
Date Sample Rec'd. 9/17/85
Invoice No. 14074

NATURE OF SAMPLE #1 (V5993)
Naval Civil Engineering Laboratory

The gas sample, as identified above, was analyzed for saturates, unsaturates, and normal gases on

Saturates		mole %	Unsaturates	mole %	Other	mole %
METHANE	(C1)	0.100	ETHYLENE	(ND)*	HYDROGEN	(ND)*
ETHANE	(C2)	(ND)*	ACETYLENE	(ND)*	CARBON MONOXIDE	(ND)*
PROPANE	(C3)	(ND)*	PROPYLENE	(ND)*	CARBON DIOXIDE	9.974
ISO-BUTANE	(IC4)	(ND)*	PROPADIENE	(ND)*	OXYGEN	8.461
N-BUTANE	(C4)	(ND)*	1-BUTENE	(ND)*	NITROGEN	81.465
ISO-PENTANE	(IC5)	(ND)*	ISO-BUTYLENE	(ND)*		
N-PENTANE	(C5)	(ND)*	TRANS-BUTENE-2	(ND)*		
HEXANE	(C6+)	(ND)*	CIS-BUTENE	(ND)*		
			1,3-BUTADIENE	(ND)*		

*Not Detected - Below limit of detection (<0.05)

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CHEMICAL RESEARCH LABORATORIES

11631 SEABOARD CIRCLE (213) 598-0458
STANTON, CA 90680 (714) 898-6370

LABORATORY REPORT

From: Jacobs Environmental Laboratories (CRL)
29 N. Olive Street
Ventura, CA 93001
ATTN: Mr. Thomas Mikel

Analysis No. V5994
Sampling Date 9/11/85
Date Sample Rec'd. 9/17/85
Invoice No. 14074

NATURE OF SAMPLE #2 (V5994)
Naval Civil Engineering Laboratory

The gas sample, as identified above, was analyzed for saturates, unsaturates, and normal gases on

Saturates		mole %	Unsaturates	mole %	Other	mole %
METHANE	(C1)	0.261	ETHYLENE	(ND)*	HYDROGEN	(ND)*
ETHANE	(C2)	(ND)*	ACETYLENE	(ND)*	CARBON MONOXIDE	(ND)*
PROPANE	(C3)	(ND)*	PROPYLENE	(ND)*	CARBON DIOXIDE	12.664
ISO-BUTANE	(IC4)	(ND)*	PROPADIENE	(ND)*	OXYGEN	15.617
N-BUTANE	(C4)	(ND)*	1-BUTENE	(ND)*	NITROGEN	71.458
ISO-PENTANE	(IC5)	(ND)*	ISO-BUTYLENE	(ND)*		
N-PENTANE	(C5)	(ND)*	TRANS-BUTENE-2	(ND)*		
HEXANE	(C6+)	(ND)*	CIS-BUTENE	(ND)*		
			1,3-BUTADIENE	(ND)*		

*Not Detected - Below limit of detection (<0.05)

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CHEMICAL RESEARCH LABORATORIES Date

CHEMICAL RESEARCH LABORATORIES

11631 SEABOARD CIRCLE (213) 598-0458
STANTON, CA 90680 (714) 898-6370

LABORATORY REPORT

From: Jacobs Environmental Laboratories(CRL)
29 N. Olive Street
Ventura, CA 93001
ATTN: Mr. Thomas Mikel

Analysis No. V5995
Sampling Date 9/11/85
Date Sample Rec'd. 9/17/85
Invoice No. 14074

NATURE OF SAMPLE #3 (V5995)
Naval Civil Engineering Laboratory

The gas sample, as identified above, was analyzed for saturates, unsaturates, and normal gases on

Saturates		mole %	Unsaturates	mole %	Other	mole %
METHANE	(C1)	0.972	ETHYLENE	(ND)*	HYDROGEN	(ND)*
ETHANE	(C2)	(ND)*	ACETYLENE	(ND)*	CARBON MONOXIDE	(ND)*
PROPANE	(C3)	(ND)*	PROPYLENE	(ND)*	CARBON DIOXIDE	13.963
ISO-BUTANE	(IC4)	(ND)*	PROPADIENE	(ND)*	OXYGEN	15.013
N-BUTANE	(C4)	(ND)*	1-BUTENE	(ND)*	NITROGEN	70.052
ISO-PENTANE	(IC5)	(ND)*	ISO-BUTYLENE	(ND)*		
N-PENTANE	(C5)	(ND)*	TRANS-BUTENE-2	(ND)*		
HEXANE	(C6+)	(ND)*	CIS-BUTENE	(ND)*		
			1,3-BUTADIENE	(ND)*		

*Not Detected - Below limit of detection (<0.05)

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CHEMICAL RESEARCH LABORATORIES Date

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LABORATORY REPORT

11631 SEABOARD CIRCLE (213) 598-0458
STANTON, CA 90680 (714) 898-6370

From: Jacobs Environmental Laboratories (CRL)
29 N. Olive Street
Ventura, CA 93001
ATTN: Mr. Thomas Mikel

Analysis No. V5996
Sampling Date 9/11/85
Date Sample Rec'd. 9/17/85
Invoice No. 14074

NATURE OF SAMPLE #4 (V5996)
Naval Civil Engineering Laboratory

The gas sample, as identified above, was analyzed for saturates, unsaturates, and normal gases on

Saturates		mole %	Unsaturates	mole %	Other	mole %
METHANE	(C1)	0.394	ETHYLENE	(ND)*	HYDROGEN	(ND)*
ETHANE	(C2)	(ND)*	ACETYLENE	(ND)*	CARBON MONOXIDE	(ND)*
PROPANE	(C3)	(ND)*	PROPYLENE	(ND)*	CARBON DIOXIDE	10.392
ISO-BUTANE	(IC4)	(ND)*	PROPADIENE	(ND)*	OXYGEN	6.364
N-BUTANE	(C4)	(ND)*	1-BUTENE	(ND)*	NITROGEN	82.850
ISO-PENTANE	(IC5)	(ND)*	ISO-BUTYLENE	(ND)*		
N-PENTANE	(C5)	(ND)*	TRANS-BUTENE-2	(ND)*		
HEXANE	(C6+)	(ND)*	CIS-BUTENE	(ND)*		
			1,3-BUTADIENE	(ND)*		

*Not Detected - Below limit of detection (<0.05)

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CHEMICAL RESEARCH LABORATORIES Date

Appendix D

TEST RESULTS ON AC PAVEMENT EMITTED GAS SAMPLES

CHEMICAL RESEARCH LABORATORIES

LABORATORY REPORT

11631 SEABOARD CIRCLE (213) 598-0458
STANTON, CA 90680 (714) 898-6370

From: Jacobs Environmental Laboratories
29 N. Olive Street
Ventura, CA 93001
ATTN: Mr. Thomas Mikel

Analysis No. V5940
Sampling Date 9/4/85
Date Sample Rec'd. 9/5/85
Invoice No. 14207

NATURE OF SAMPLE Naval Civil Engineers Lab - 8509016 Asphalt #1 Ambient

The gas sample, as identified above, was analyzed for saturates, unsaturates, and normal gases on

Saturates		mole %	Unsaturates	mole %	Other	mole %
METHANE	(C1)	(ND)*	ETHYLENE	(ND)*	HYDROGEN	(ND)*
ETHANE	(C2)	(ND)*	ACETYLENE	(ND)*	CARBON MONOXIDE	(ND)*
PROPANE	(C3)	(ND)*	PROPYLENE	(ND)*	CARBON DIOXIDE	0.071
ISO-BUTANE	(IC4)	(ND)*	PROPADIENE	(ND)*	OXYGEN	13.066
N-BUTANE	(C4)	(ND)*	1-BUTENE	(ND)*	NITROGEN	86.863
ISO-PENTANE	(IC5)	(ND)*	ISO-BUTYLENE	(ND)*		
N-PENTANE	(C5)	(ND)*	TRANS-BUTENE-2	(ND)*		
HEXANE	(C6+)	(ND)*	CIS-BUTENE	(ND)*		
			1,3-BUTADIENE	(ND)*		

*Not Detected - Below limit of detection (<0.05)

Analysis was performed on 50.1 of sample maintained at ambient conditions for 5 days.

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[signature]
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CHEMICAL RESEARCH LABORATORIES Date 10/24/85

CHEMICAL RESEARCH LABORATORIES

LABORATORY REPORT

11631 SEABOARD CIRCLE (213) 598-0458
STANTON, CA 90680 (714) 898-6370

From: Jacobs Environmental Laboratories
29 N. Olive Street
Ventura, CA 93001
ATTN: Mr. Thomas Mikel

Analysis No. V5940
Sampling Date 9/4/85
Date Sample Rec'd. 9/5/85
Invoice No. 14207

NATURE OF SAMPLE Naval Civil Engineers Lab - 3509016 Asphalt #1 100°F

The gas sample, as identified above, was analyzed for saturates, unsaturates, and normal gases on

Saturates		mole %	Unsaturates	mole %	Other	mole %
METHANE	(C1)	(ND)*	ETHYLENE	(ND)*	HYDROGEN	(ND)*
ETHANE	(C2)	(ND)*	ACETYLENE	(ND)*	CARBON MONOXIDE	(ND)*
PROPANE	(C3)	(ND)*	PROPYLENE	(ND)*	CARBON DIOXIDE	(ND)*
ISO-BUTANE	(IC4)	(ND)*	PROPADIENE	(ND)*	OXYGEN	19.755
N-BUTANE	(C4)	(ND)*	1-BUTENE	(ND)*	NITROGEN	80.245
ISO-PENTANE	(IC5)	(ND)*	ISO-BUTYLENE	(ND)*		
N-PENTANE	(C5)	(ND)*	TRANS-BUTENE-2	(ND)*		
HEXANE	(C6+)	(ND)*	CIS-BUTENE	(ND)*		
			1,3-BUTADIENE	(ND)*		

*Not Detected - Below limit of detection (<0.05)

Analysis was performed on 50.2g of sample incubated @ 100°F for 5 days.

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CHEMICAL RESEARCH LABORATORIES

11631 SEABOARD CIRCLE (213) 598-0458
STANTON, CA 90680 (714) 898-6370

LABORATORY REPORT

From: Jacobs Environmental Laboratories
29 N. Olive Street
Ventura, CA 93001
ATTN: Mr. Thomas Mikel

Analysis No. V5940
Sampling Date 9/4/85
Date Sample Rec'd. 9/5/85
Invoice No. 14207

NATURE OF SAMPLE Naval Civil Engineers Lab - 8509016 Asphalt #1 125°F

The gas sample, as identified above, was analyzed for saturates, unsaturates, and normal gases on

Saturates		mole %	Unsaturates	mole %	Other	mole %
METHANE	(C1)	(ND)*	ETHYLENE	(ND)*	HYDROGEN	(ND)*
ETHANE	(C2)	(ND)*	ACETYLENE	(ND)*	CARBON MONOXIDE	(ND)*
PROPANE	(C3)	(ND)*	PROPYLENE	(ND)*	CARBON DIOXIDE	(ND)*
ISO-BUTANE	(IC4)	(ND)*	PROPADIENE	(ND)*	OXYGEN	20.048
N-BUTANE	(C4)	(ND)*	1-BUTENE	(ND)*	NITROGEN	79.952
ISO-PENTANE	(IC5)	(ND)*	ISO-BUTYLENE	(ND)*		
N-PENTANE	(C5)	(ND)*	TRANS-BUTENE-2	(ND)*		
HEXANE	(C6+)	(ND)*	CIS-BUTENE	(ND)*		
			1,3-BUTADIENE	(ND)*		

*Not Detected - Below limit of detection (<0.05)

Analysis was performed on 51.1g of sample incubated @ 125°F for 5 days.

CA
ANALYST

Reviewed & Approved
CHEMICAL RESEARCH LABORATORIES Date 10/24/85

CHEMICAL RESEARCH LABORATORIES

11631 SEABOARD CIRCLE (213) 598-0458
STANTON, CA 90680 (714) 898-6370

LABORATORY REPORT

From: Jacobs Environmental Laboratories
29 N. Olive Street
Ventura, CA 93001
ATTN: Mr. Thomas Mikel

Analysis No. V5941
Sampling Date 9/4/85
Date Sample Rec'd. 9/5/85
Invoice No. 14207

NATURE OF SAMPLE Naval Civil Engineers Lab - 8509016 Asphalt #3 100°F

The gas sample, as identified above, was analyzed for saturates, unsaturates, and normal gases on

Saturates		mole %	Unsaturates	mole %	Other	mole %
METHANE	(C1)	(ND)*	ETHYLENE	(ND)*	HYDROGEN	(ND)*
ETHANE	(C2)	(ND)*	ACETYLENE	(ND)*	CARBON MONOXIDE	(ND)*
PROPANE	(C3)	(ND)*	PROPYLENE	(ND)*	CARBON DIOXIDE	0.207
ISO-BUTANE	(IC4)	(ND)*	PROPADIENE	(ND)*	OXYGEN	19.963
N-BUTANE	(C4)	(ND)*	1-BUTENE	(ND)*	NITROGEN	79.830
ISO-PENTANE	(IC5)	(ND)*	ISO-BUTYLENE	(ND)*		
N-PENTANE	(C5)	(ND)*	TRANS-BUTENE-2	(ND)*		
HEXANE	(C6+)	(ND)*	CIS-BUTENE	(ND)*		
			1,3-BUTADIENE	(ND)*		

*Not Detected - Below limit of detection (<0.05)

Analysis was performed on 50.2g of sample incubated at 100°F for 5 days.

CA
ANALYST

REVIEWED & APPROVED
CHEMICAL RESEARCH LABORATORIES Date 10/24/85

CHEMICAL RESEARCH LABORATORIES

LABORATORY REPORT

11631 SEABOARD CIRCLE (213) 598-0458
STANTON, CA 90680 (714) 898-6370

From: Jacobs Environmental Laboratories
29 N. Olive Street
Ventura, CA 93001
ATTN: Mr. Thomas Mikel

Analysis No. V5941
Sampling Date 9/4/85
Date Sample Rec'd. 9/5/85
Invoice No. 14207

NATURE OF SAMPLE Naval Civil Engineers Lab - 8509016 Asphalt #3 125°F

The gas sample, as identified above, was analyzed for saturates, unsaturates, and normal gases on

Saturates		mole %	Unsaturates	mole %	Other	mole %
METHANE	(C1)	(ND)*	ETHYLENE	(ND)*	HYDROGEN	(ND)*
ETHANE	(C2)	(ND)*	ACETYLENE	(ND)*	CARBON MONOXIDE	(ND)*
PROPANE	(C3)	(ND)*	PROPYLENE	(ND)*	CARBON DIOXIDE	0.345
ISO-BUTANE	(IC4)	(ND)*	PROPADIENE	(ND)*	OXYGEN	19.065
N-BUTANE	(C4)	(ND)*	1-BUTENE	(ND)*	NITROGEN	80.590
ISO-PENTANE	(IC5)	(ND)*	ISO-BUTYLENE	(ND)*		
N-PENTANE	(C5)	(ND)*	TRANS-BUTENE-2	(ND)*		
HEXANE	(C6+)	(ND)*	CIS-BUTENE	(ND)*		
			1,3-BUTADIENE	(ND)*		

*Not Detected - Below limit of detection (<0.05)

Analysis was performed on 50.5g of sample incubated at 125°F for 5 days.

CA
ANALYST

REVIEWED & APPROVED
CHEMICAL RESEARCH LABORATORIES Date 10/24/85

Appendix E

TEST RESULTS ON AC PAVEMENT SAMPLES

ATEC Associates, Inc.
of Savannah
118 Main Street/Garden City, Georgia 31408
912/964-6261

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District Affiliates:
Beckley, WV
Norfolk, VA

October 21, 1985

Comptroller
Naval Construction Battalion Center
Port Hueneme, CA 93043

Attention: Mr. Mel Hironaka

Subject: REPORT OF BITUMINOUS MIXTURE ANAYLSIS
PAVEMENT BLISTERING INVESTIGATION
Marine Corps Air Station, Beaufort, SC
Code: 09A224
CONTRACT N62467-85-C-0619

Date of Sample: Unknown
Date Received: 9-10-85
Taken by: Client

Identification: Sample #1
Lab Number: 1274

Aggregate Gradation ASTM C-117:

U.S. Sieve Size	Cumulative Passing %
1/2"	100.0
3/8"	95.9
4	76.6
8	58.3
16	46.4
30	37.8
50	31.1
100	13.3
200	6.6

Bitumen, % of total mix: 5.7
ASTM D-2172

Moisture, %: 0.2
ASTM D-1461

Max. Spec. Gravity (ZAVD): 2.435
Density, P.C.F.: 151.94
ASTM D-2041

Pavement or Core data:
Specific Gravity: 2.248
Density, P.C.F.: 140.28
ASTM D-2726

Air Voids, %: 7.7
ASTM D-2041

Stripping Test: 85-95%
ASTM D-3625 Coating Retained

Asphalt recovered by the
Abson Method:
*Penetration @ 77°F: 20
ASH, %: 0.49
**Viscosity Absolute @140°F: 33,930

*ASTM D-5
**ASTM D-2171

Naval Construction Battalion Center
Port Hueneme, CA 93043
Page Two

Date of Sample: Unknown
Date Received: 9-10-85
Taken by: Client

Indentification: Sample #2
Lab Number: 1275

Aggregate Gradation ASTM C-117

U.S.Sieve Size	Cumulative Passing %
1/2"	100.0
3/8"	94.7
4	71.0
8	54.1
16	43.4
30	37.3
50	32.2
100	12.4
200	5.9

Bitumen, % of total mix: 5.8
ASTM D-2172

Moisture, %: 0.2
ASTM D-1461

Max. Spec. Gravity (ZAVD): 2.395
Density, P.C.F.: 149.45
ASTM D-2041

Pavement or Core data:
Specific Gravity: 2.266
Density, P.C.F.: 141.39
ASTM D-2726

Air Voids, %: 5.4
ASTM D-2041

Stripping Test: 95 + 90
ASTM D-3625 Coating Retained

Asphalt recovered by the
Abson Method:
*Penetration @ 77°F: 31
ASH, %: 0.41
**Viscosity Absolute @ 140°F: 39,260

*ASTM D-5
**ASTM D-2171

We appreciate this opportunity to be of service to you. If you have any questions concerning this report, or if we can be of further assistance, please do not hesitate to call.

Sincerely,

ATEC ASSOCIATES, INC.

Jack Harper

Joe Harper
Branch Manager/Materials Testing

JH:go

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MCAS CO. Helicopter. Jacksonville. NC; Facil. Engr. Div. Cherry Point NC
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MCAS Fac Offr. Iwakuni. Japan; Facs Maint Dept - Operations Div. Cherry Point; PW Engrg (J Paschal). Beaufort. SC; PWO - Santa Ana. CA; PWO. Beaufort. SC; PWO. Kaneohe Bay. HI
MCLB PWO. Barstow CA
NAF Dir. Engrg Div. PWD. Atsugi. Japan; PWO. Mount Clemens MI
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